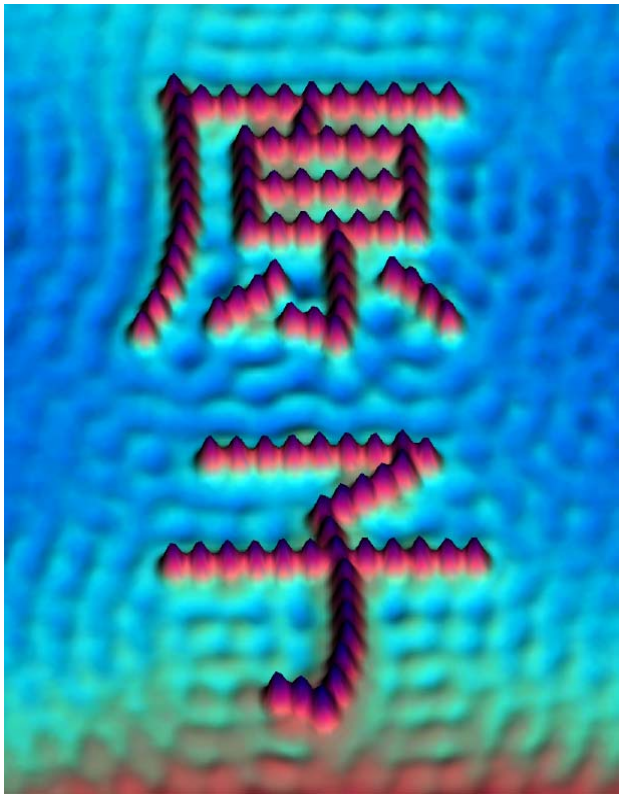


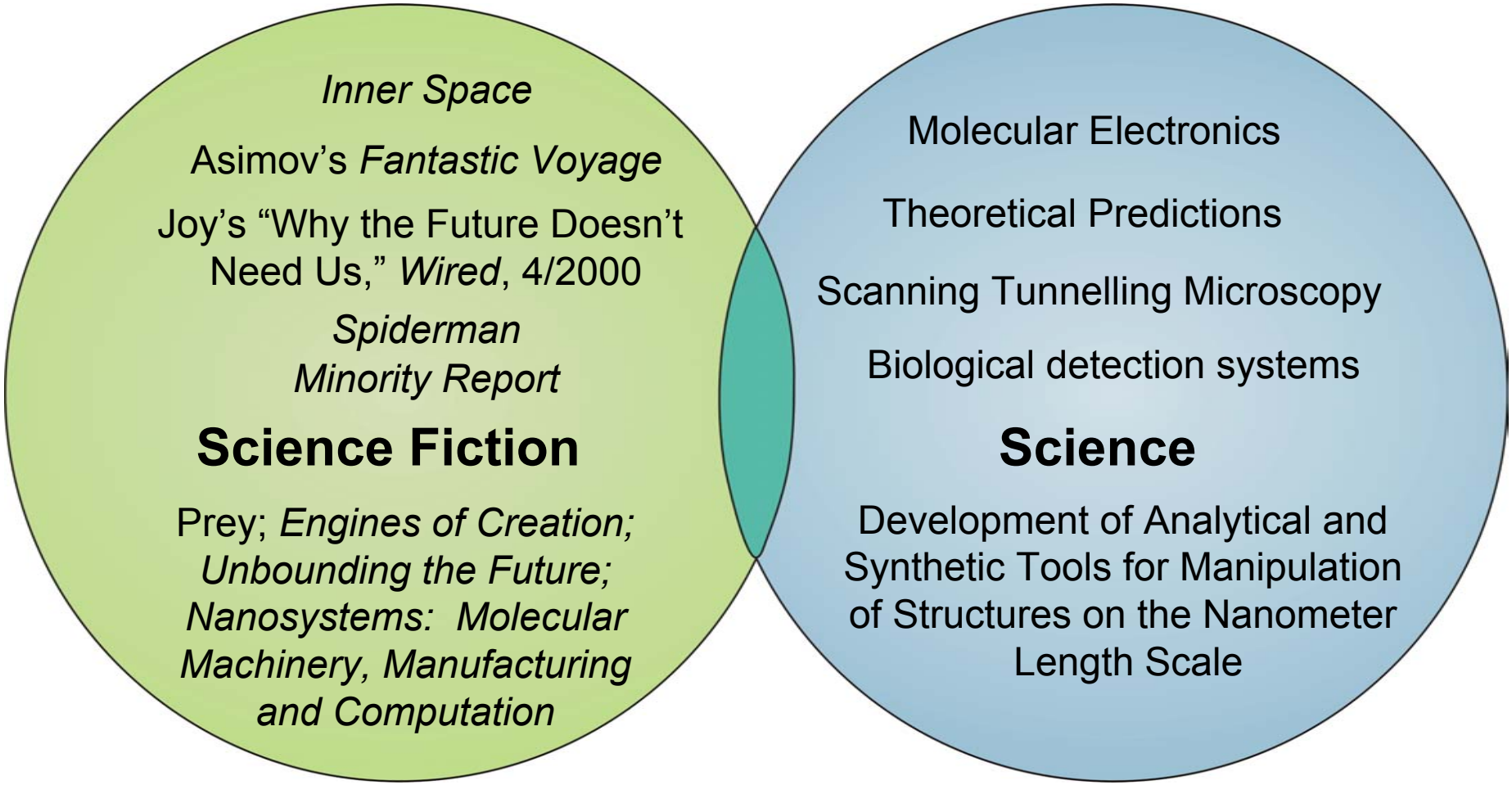
The Kanji characters for "atom“
Iron on copper III *(Lutz & Eigler)*

Nanotechnology Overview

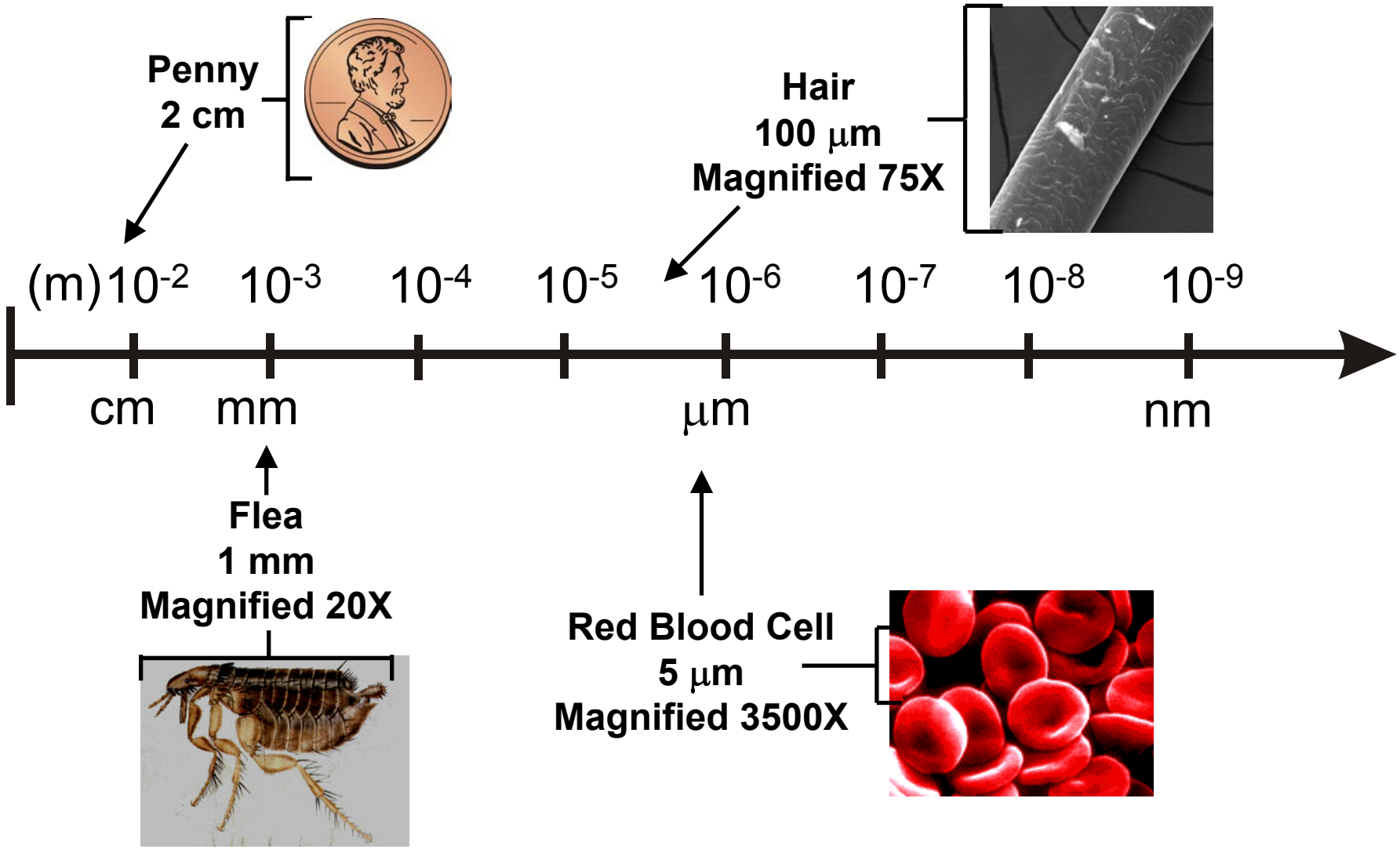
Chad A. Mirkin

Institute for Nanotechnology
Northwestern University
2190 Campus Drive
Evanston, IL 60208

Nanotechnology

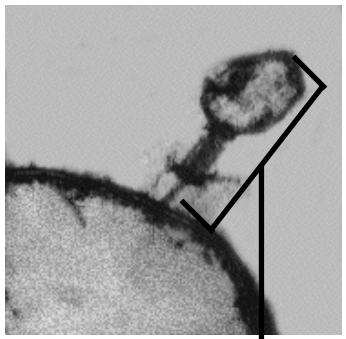


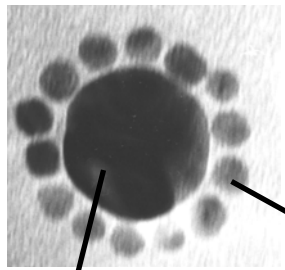
The Size of Things…



The Interesting Length Scale

Bacteriophage
60-70 nm
Magnified 400,000X

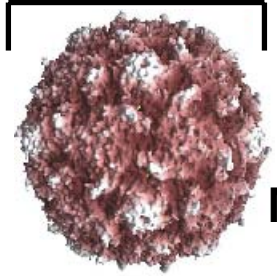




Gold Particles
13 nm & 50 nm
Magnified 500,000X

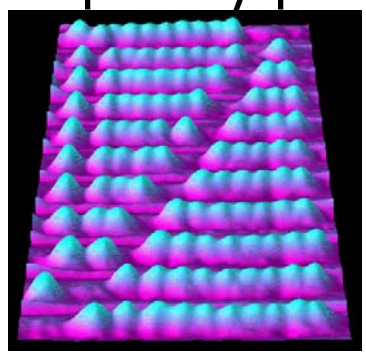
100 80 60 40 20 1

(nm)



Flu Virus
100 nm
Magnified 320,000X

World's Smallest Abacus
C_{60} Molecules on Cu(111)
1 nm C_{60} & 10nm lines
Magnified 15 millionX



Nanotechnology: What is it?

1. Developing synthetic and analytical tools for characterizing and manipulating materials on the nanometer (nm) length scale.

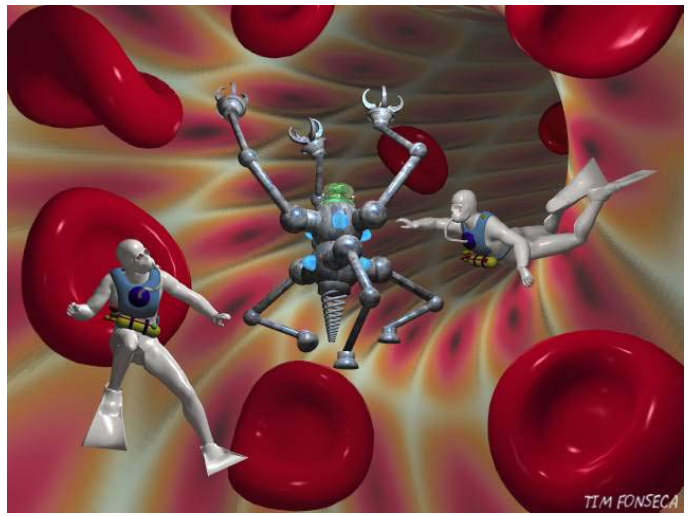
2. Determining the chemical and physical consequences of miniaturization.

3. Exploiting the ability to miniaturize and its consequences in the development of new technology.

Nanotechnology is not About Nanobots

"Smart Nanodevices..
..applied to medicine would be able
To seek out a target in the body…fix it and prevent it from further activity, for example, preventing a virus from infecting a cell."

By C.A. Haberzettl, *Nanotechnology* **13** (2002) 9-13



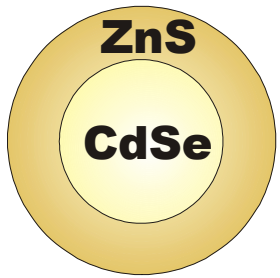
Or

Dumb (or Evil) Nanobots..

"…self-replicating microscopic robots, the size of bacteria, fill the world and wipe out humanity…"

By B.J. Feder ***The New York Times***, August 2002

Optical Properties of Semiconductor Nanoparticles

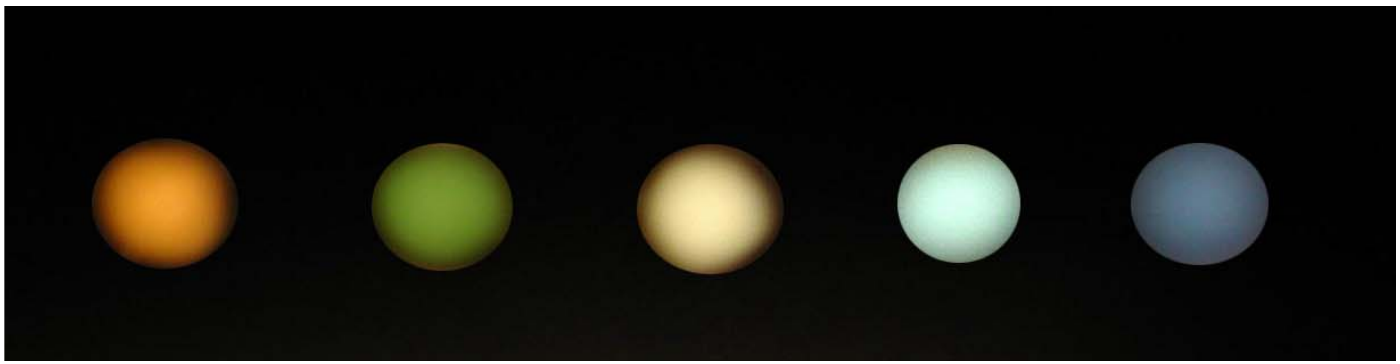


2.3 nm 4.2 nm 4.8 nm 5.5 nm

Larger Band Gap **Smaller Band Gap**

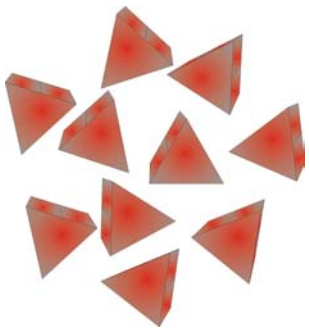
Courtesy of Bawendi and Coworkers.

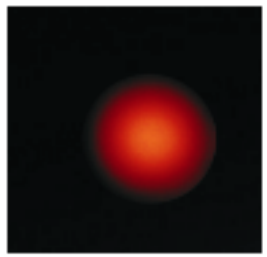
Composition Matters



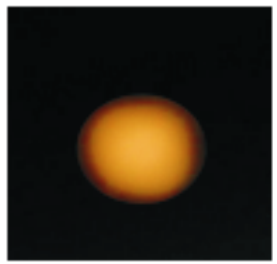
Au Spheres ~100 nm	Au Spheres ~50 nm	Ag Spheres ~100 nm	Ag Spheres ~50 nm	Ag Spheres ~26 nm

Shape Matters

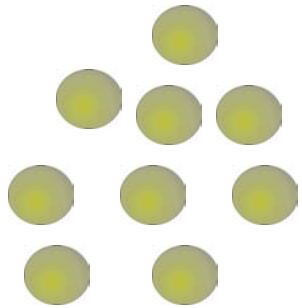


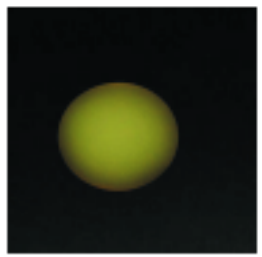


Ag
Triangles
~90 nm



Au
Rods
~100 nm

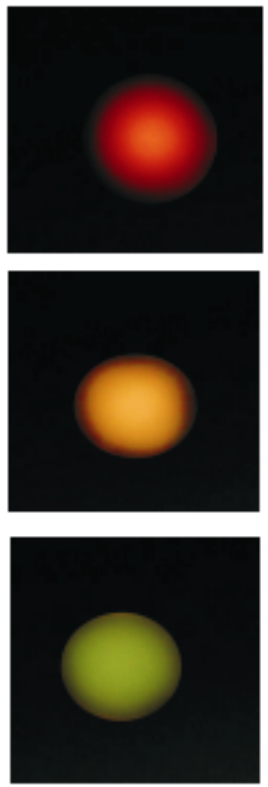




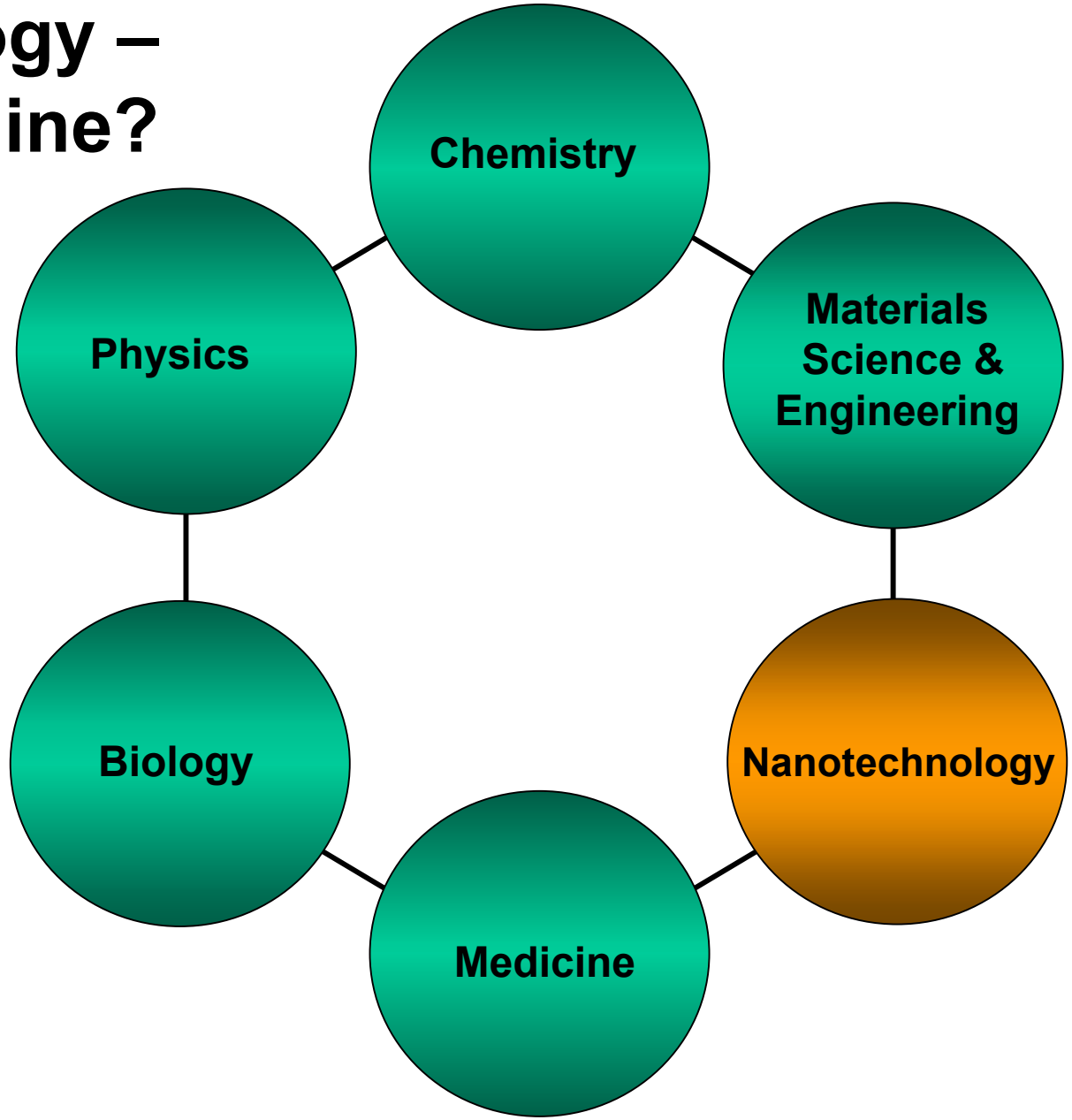
Au
Spheres
~50 nm

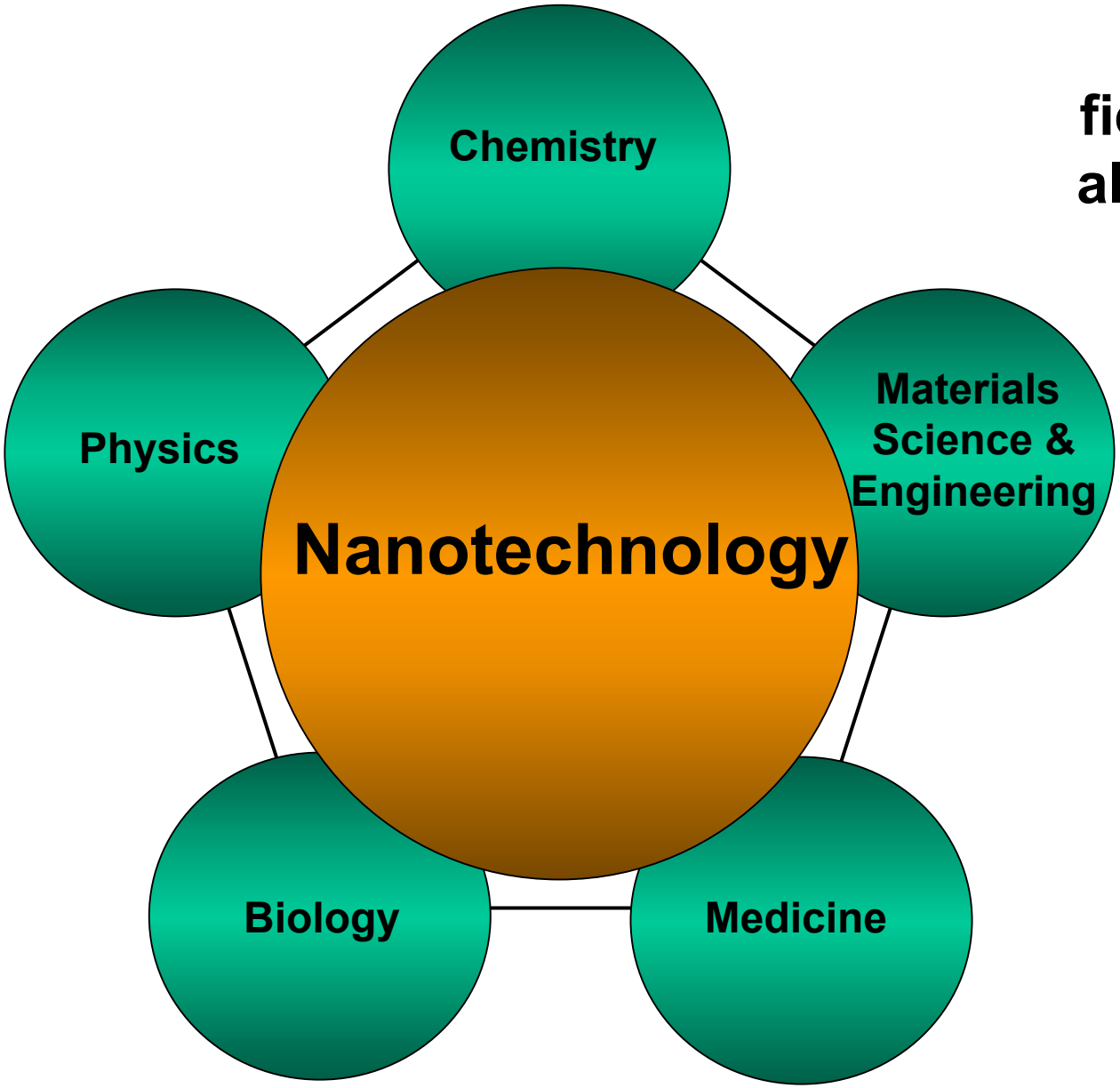
The First Technological Application

“The Nano-Stoplight”



Nanotechnology – A New Discipline?

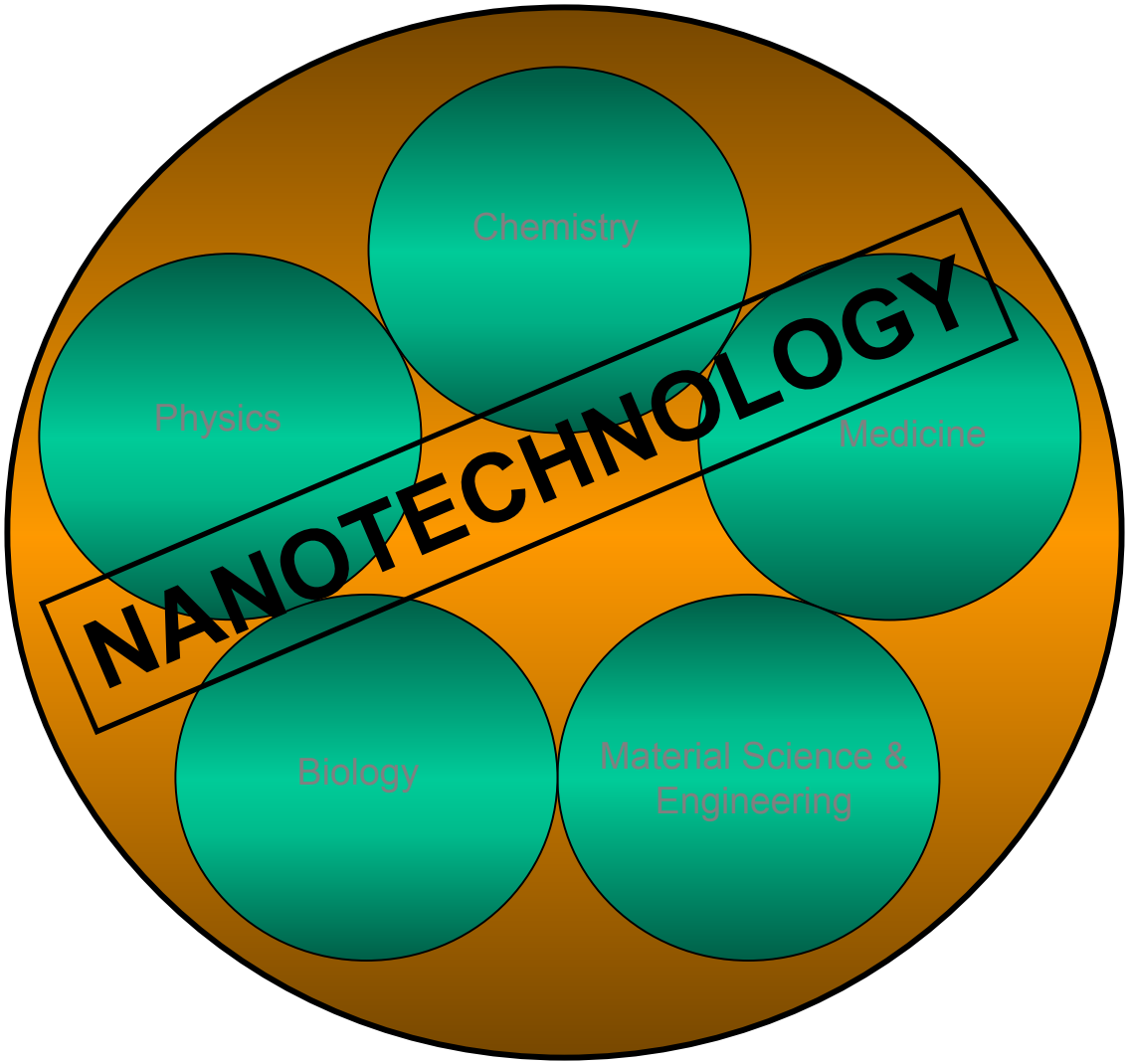




A tool driven field that impacts all subdisciplines

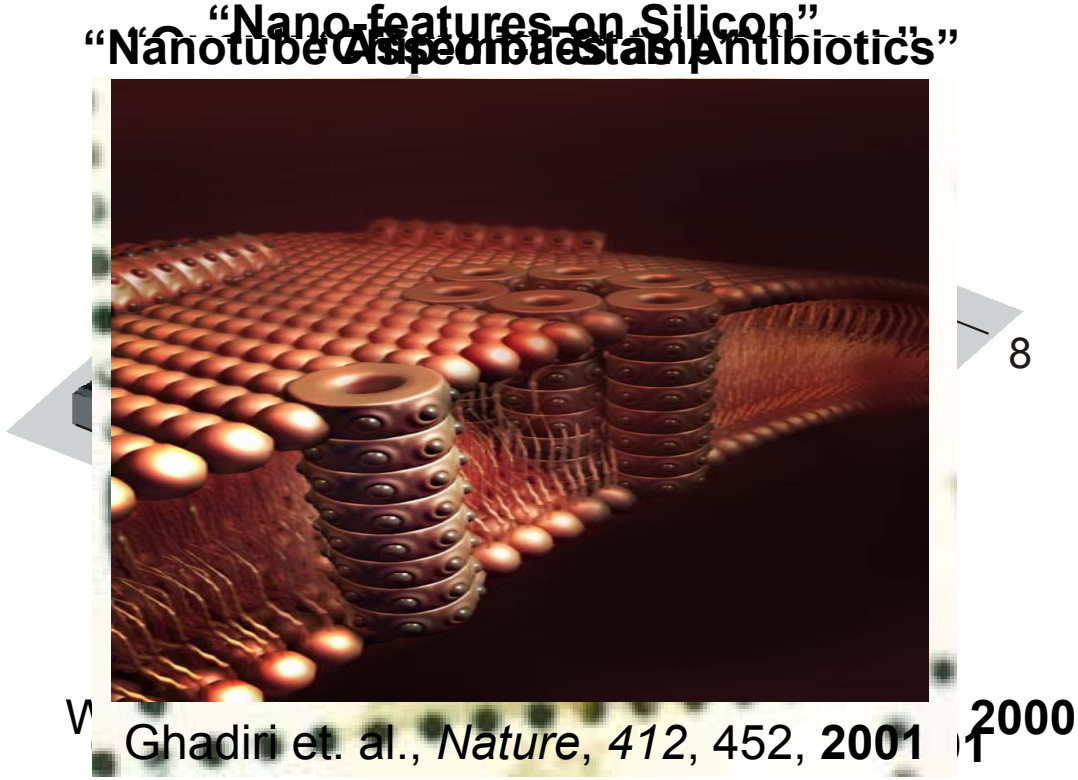
The revolution is a new way of thinking about and doing all science and engineering that is enabled by these tools.

Nanotechnology Encompasses All Fields



Economic Impact Areas

- Diagnostics
- Drug Delivery
- Materials Design
- Electronics/Computers



Ghadiri et. al., *Nature*, *412*, 452, **2001**

Manz, et. al., Imperial College, London

Institute for Nanotechnology

Center for Nanofabrication & Molecular Self-Assembly (NAMSA) 2000

- **Nanoscale Science & Engineering Center (NSEC) 2001**
- **Center for Transportation Nanotechnology (CTN) 2000**
- **Multidisciplinary Research Initiative (MURI) 2000**
- **Defense University Research Initiative on Nanotechnology (DURINT) 2000**

NU NSEC Mission

To advance the progress of science, engineering, and related education in the realm of nanoscience and nanotechnology and to develop a center of excellence in the area of nanopatterning and detection science and technology

Participants & Departmental Affiliations

Chemistry
Hilary Godwin,NU-JA
Joseph Hupp, NU
Seunghun Hong, NU
Anne Lazarides, NU
Chad Mirkin, NU
Milan Mrksich, UC
SonBinh Nguyen, NU
George Schatz, NU
Stephen Sligar, UIUC-JA
Samuel Stupp, NU-JA
Richard Van Duyne, NU

Medical School
Karen Kaul, NU
Stephen Sligar, UIUC-JA
Samuel Stupp, NU-JA

Materials Science & Engineering
Michael Bedzyk, NU-JA
R.P.H. Chang, NU-JA
Vinayak Dravid, NU
Mark Hersam, NU
Monica Olvera de la Cruz, NU
Samuel Stupp, NU-JA

Biomedical Engineering
David Kelso, NU
Annelise Barron, NU-JA
Samuel Stupp, NU-JA

Mechanical Engineering
Horacio Espinosa, NU

Chemical Engineering
Annelise Barron, NU-JA
Samuel Stupp, NU-JA

Electrical Engineering
Chang Liu, UIUC
R.P.H. Chang, NU-JA

Physics & Biophysics
Michael Bedzyk, NU-JA
Stephen Sligar, UIUC-JA

Biochemistry
Stephen Sligar, UIUC-JA
Hilary Godwin, NU-JA

Educational Outreach Partners

Museum of
Science and Industry - Chicago

Barry Aprison, Director of Science and Technology, MSI

Harold Washington College

Thomas Higgins, Professor, Physical Sciences

Dennis Lehman, Professor, Physical Sciences

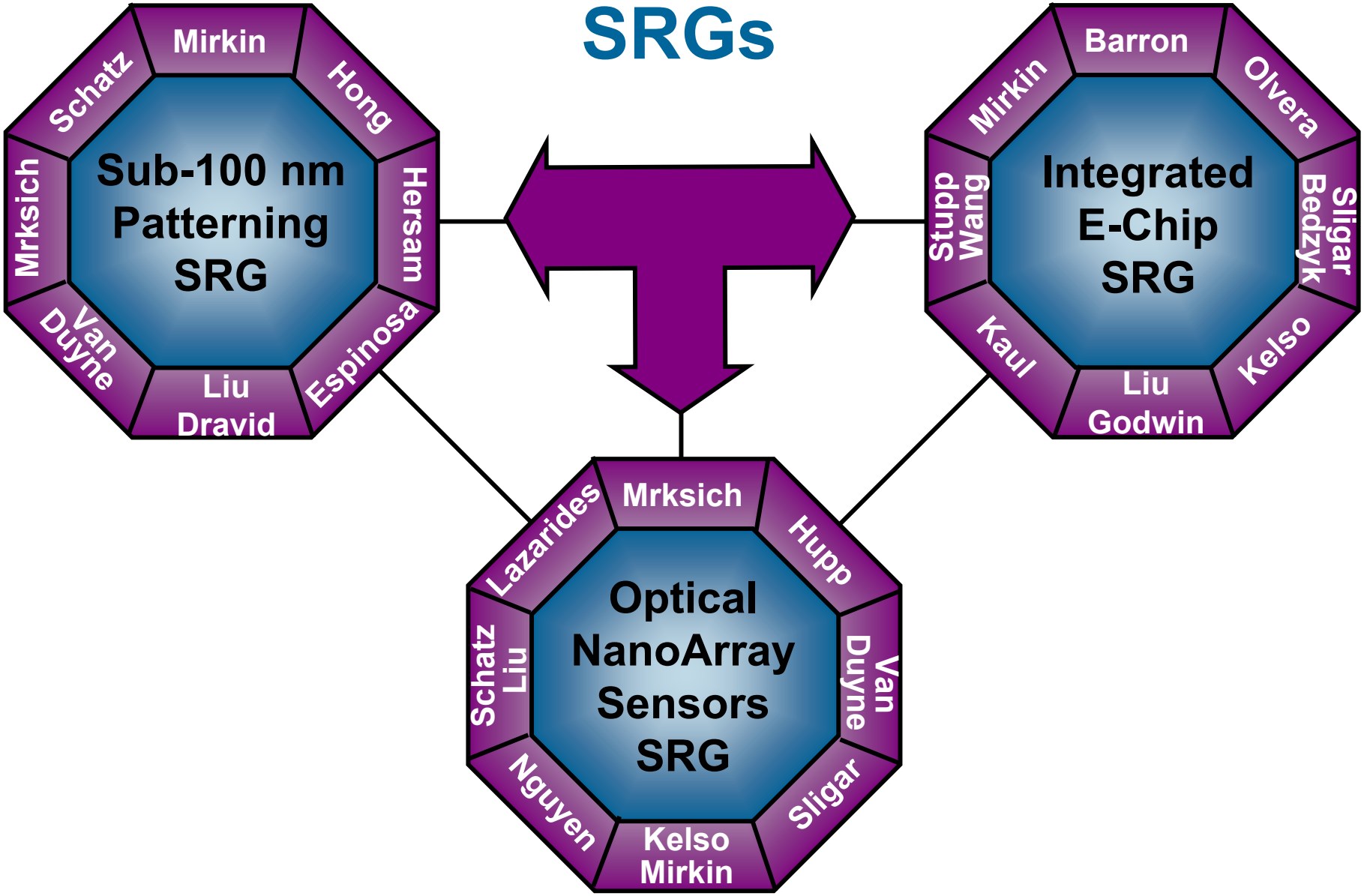
Kellogg School of
Management

Barry Merkin, Professor

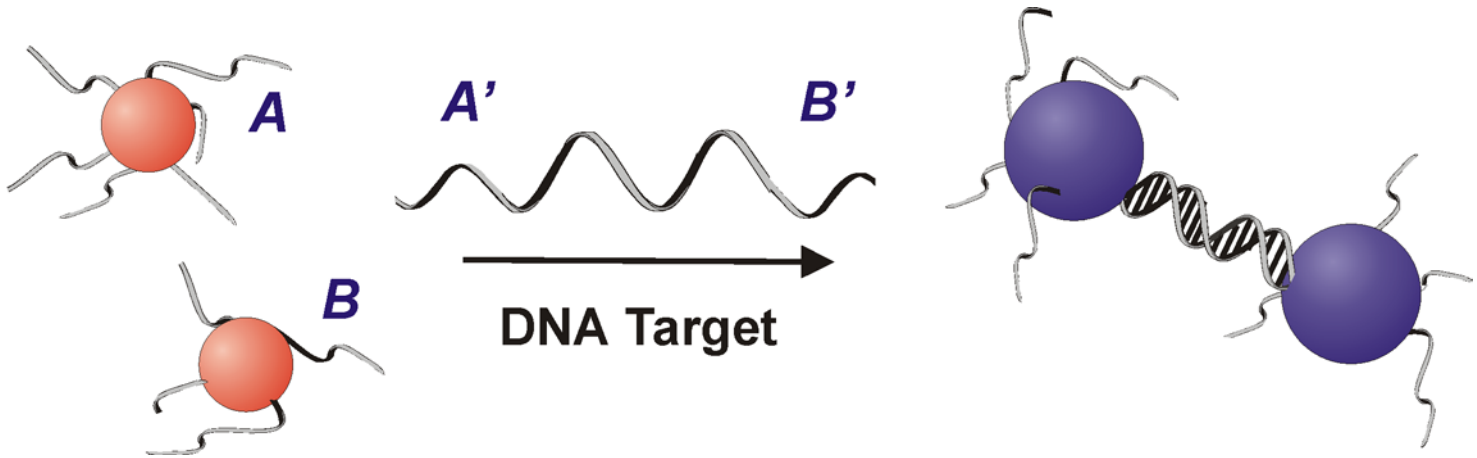
Center Goals

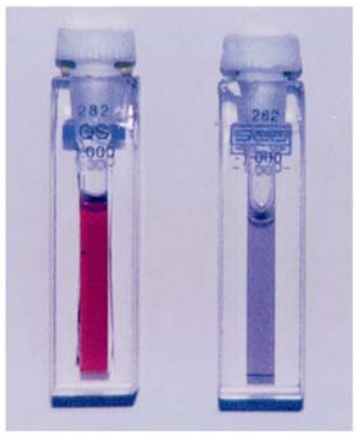
1. **Address complex, interdisciplinary challenges in nanoscale science and engineering through the development of state-of-the-art nanopatterning tools -- with an emphasis on detection science and technology**
2. Provide an effective and comprehensive educational program which fosters a lifelong interest in science and technology by teaching people of all ages about nanoscience and nanotechnology
3. Support effective partnerships with industry, government labs, and other users of research outcomes

SRGs

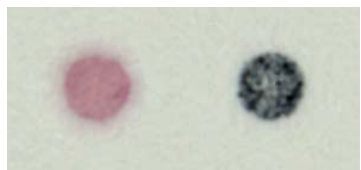

Sub-100 nm Patterning SRG
Mirkin
Hong
Hersam
Espinosa
Liu
Dravid
Van Duyne
Mrksich
Schatz
Integrated E-Chip SRG
Barron
Olvera
Sligar
Bedzyk
Kelso
Liu
Godwin
Kaul
Stupp
Wang
Mirkin
Optical NanoArray Sensors SRG
Mrksich
Hupp
Van Duyne
Sligar
Kelso
Mirkin
Nguyen
Schatz
Liu
Lazarides

DNA Detection with Nanoprobes



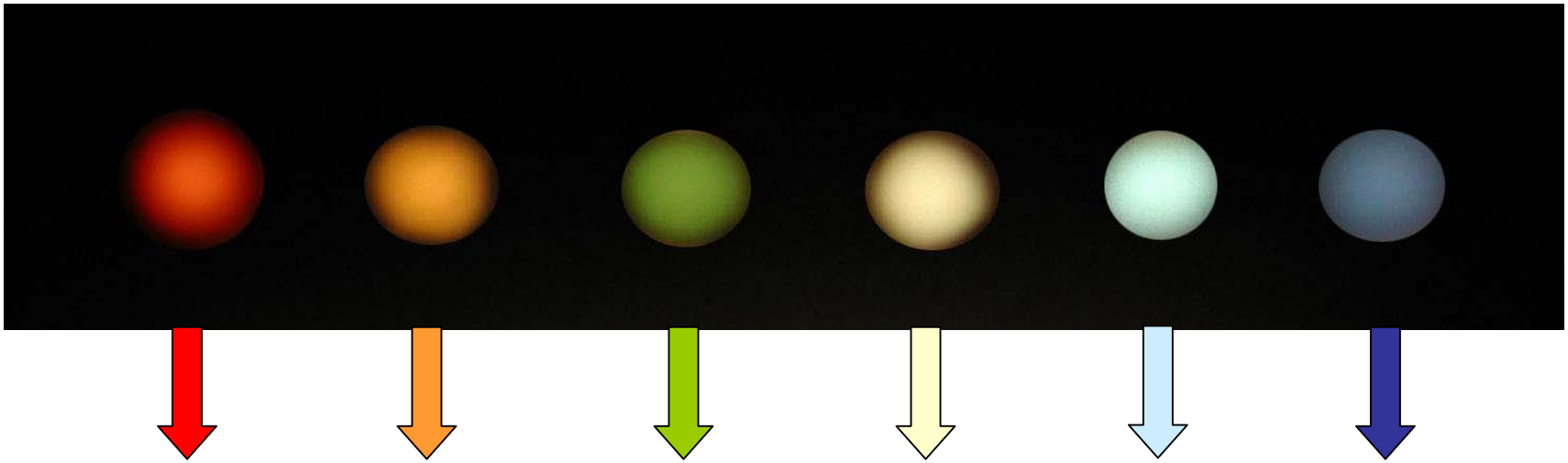


without target | with target

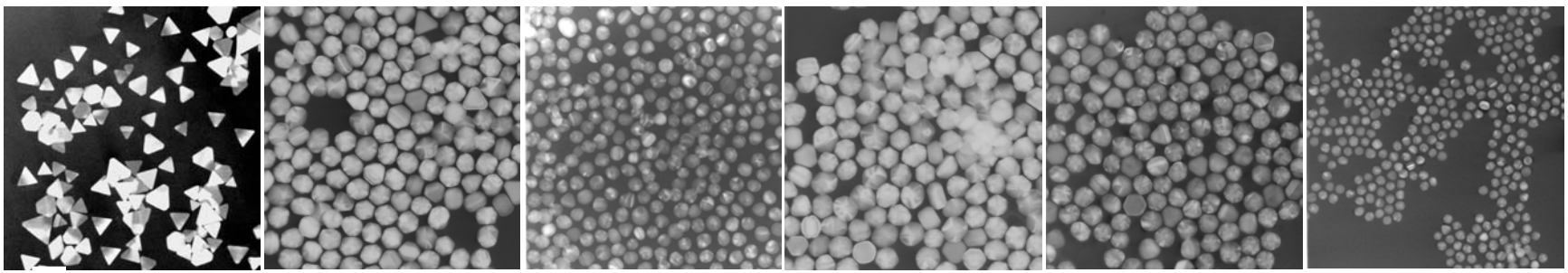


DNA Litmus Test

Rayleigh Light Scattering of Nanoparticles: Size, Shape, and Composition Matters

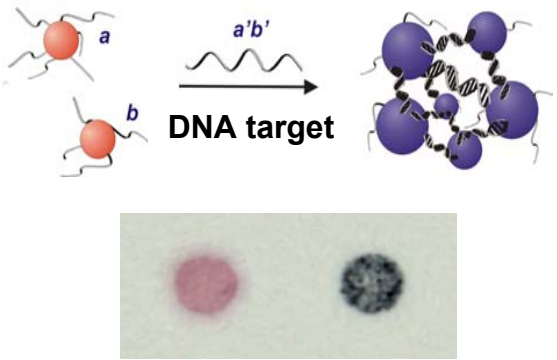


Ag Nanoprisms ~100 nm	Au Spheres ~100 nm	Au Spheres ~50 nm	Ag Spheres ~100 nm	Ag Spheres ~80 nm	Ag Spheres ~40 nm

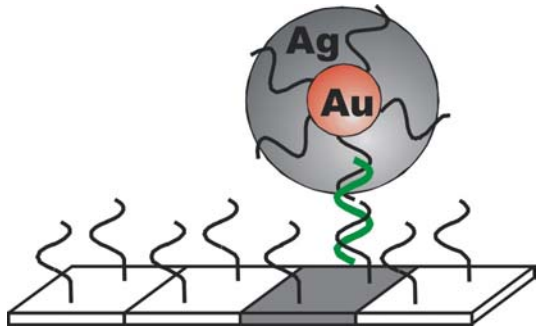


200nm (the same for all the images)

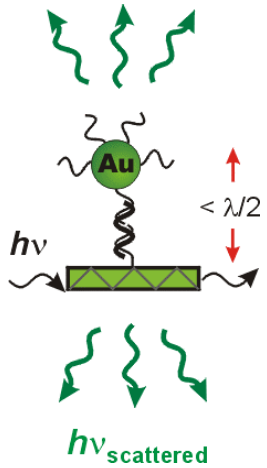
Nanoparticle-Based DNA Detection Methods



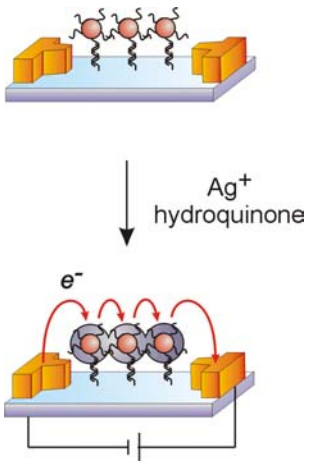
Spot Test
Science, 1997
JACS, 1998



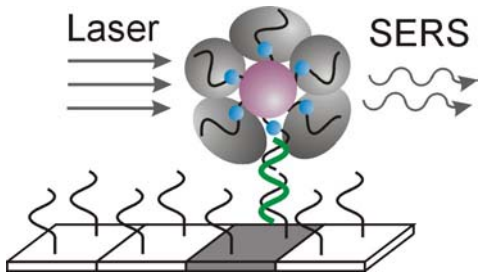
Silver-Staining
Science, 2000



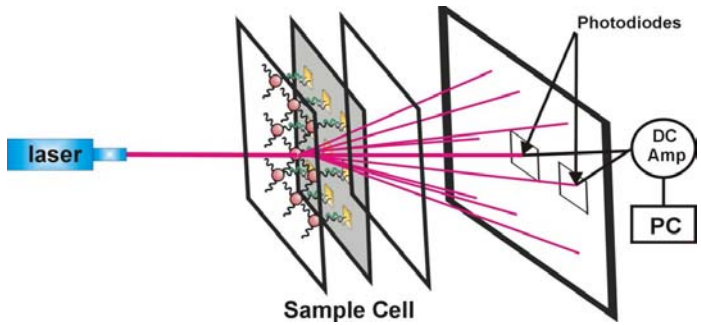
White Light
JACS, 2000



Electrical
Science, 2002

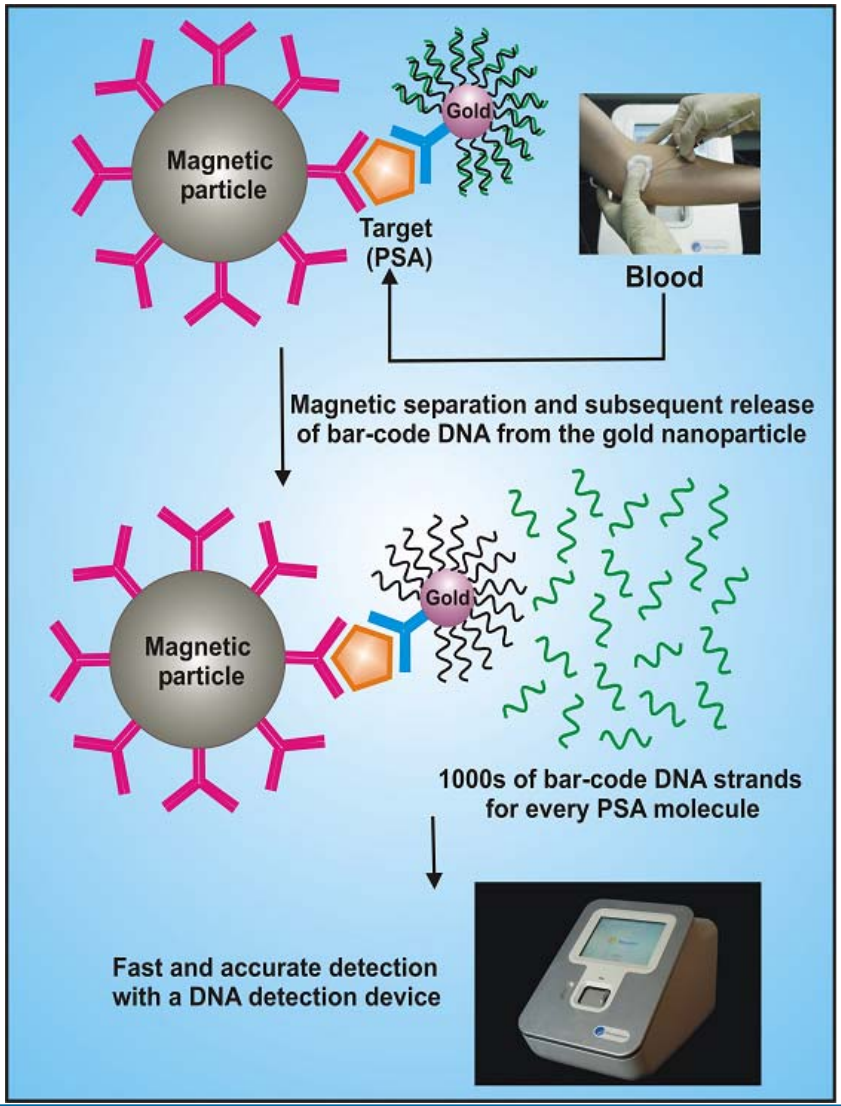


Raman
Science, 2002



Laser & Diffraction Grating
JACS, 2003

“Biobarcodes”



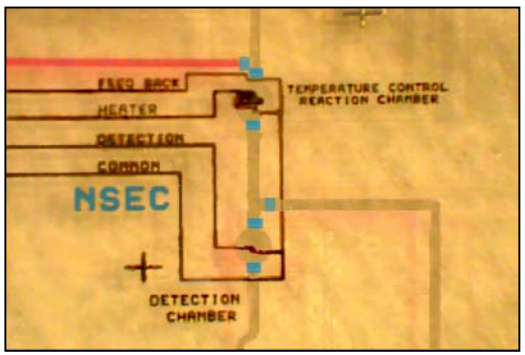
Published in *Science* September 26, 2003.

The technology: An assay for protein biomarkers that can screen for many targets simultaneously with 6 orders of magnitude greater sensitivity than clinical ELISA-based assays.

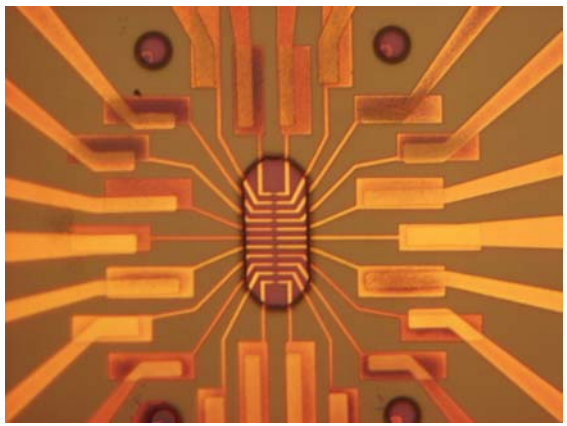
Payoff: PCR-like sensitivity for protein markers – it will revolutionize protein-based biodiagnostics much like PCR revolutionized DNA diagnostics.

Working with Nanosphere, Inc. (Northbrook, IL) to commercialize the technology (target: 2 years).

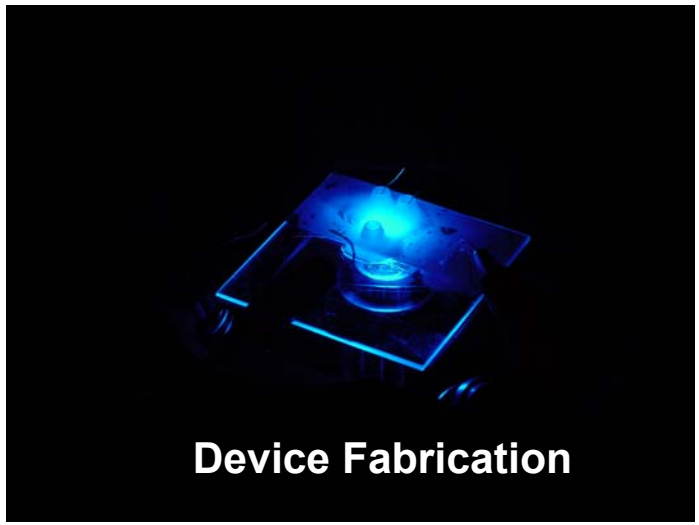
Can these advances in nanoscience be translated into the world's first generally useful point-of-care diagnostics systems for biomarkers?



Sample Handling and Microfluidics



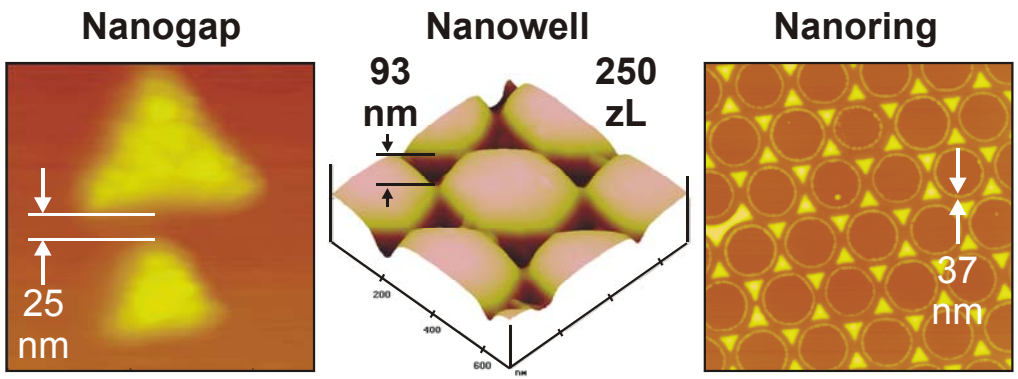
Micro- and Nanofabrication of Hardware



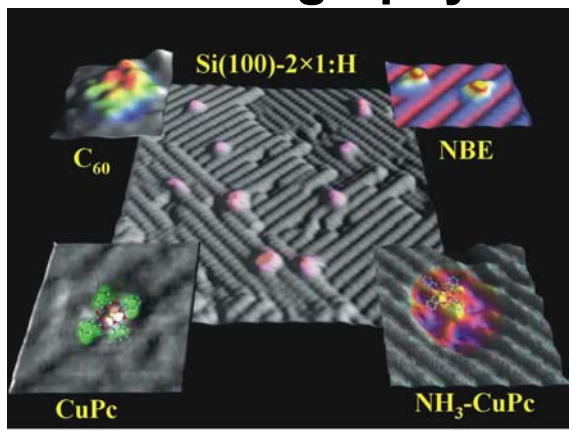
Device Integration

Nanolithographic Tools Developed Within the NSEC

Nanosphere Lithography

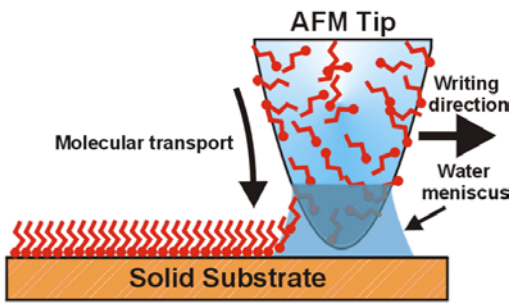


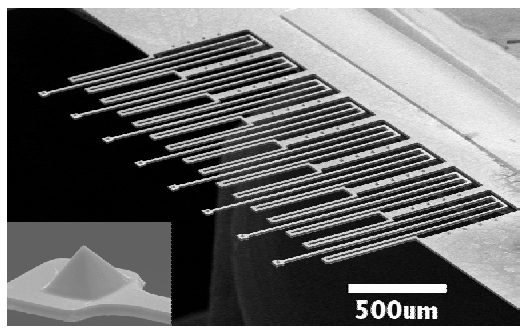
Feedback Controlled Lithography



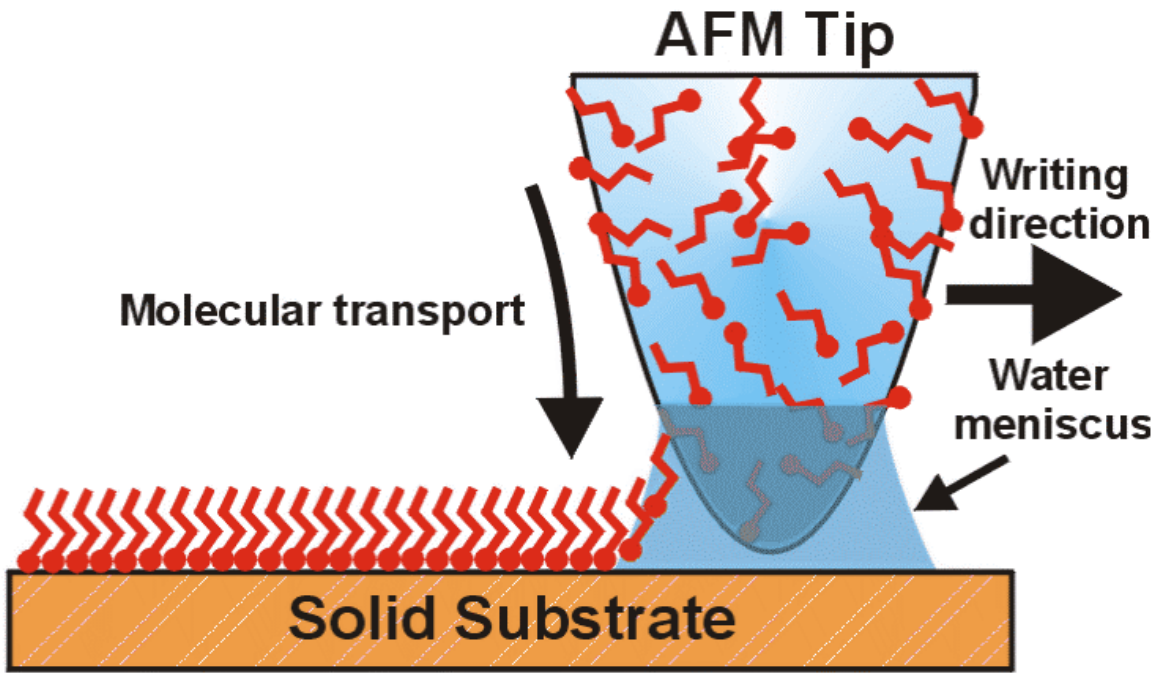
17 nm by 17 nm STM image following FCL patterning of eight silicon dangling bonds. The four insets illustrate four intentionally isolated molecules.

Dip-Pen Nanolithograpy

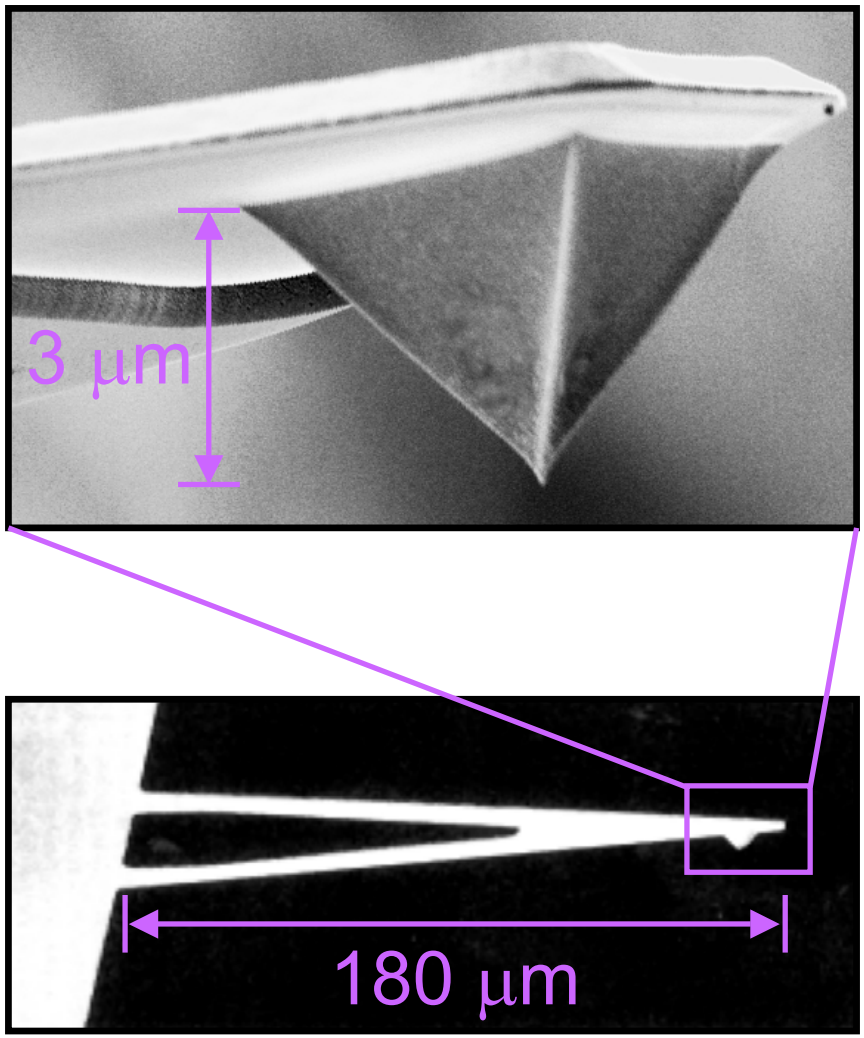




Dip Pen Nanolithography (DPN)



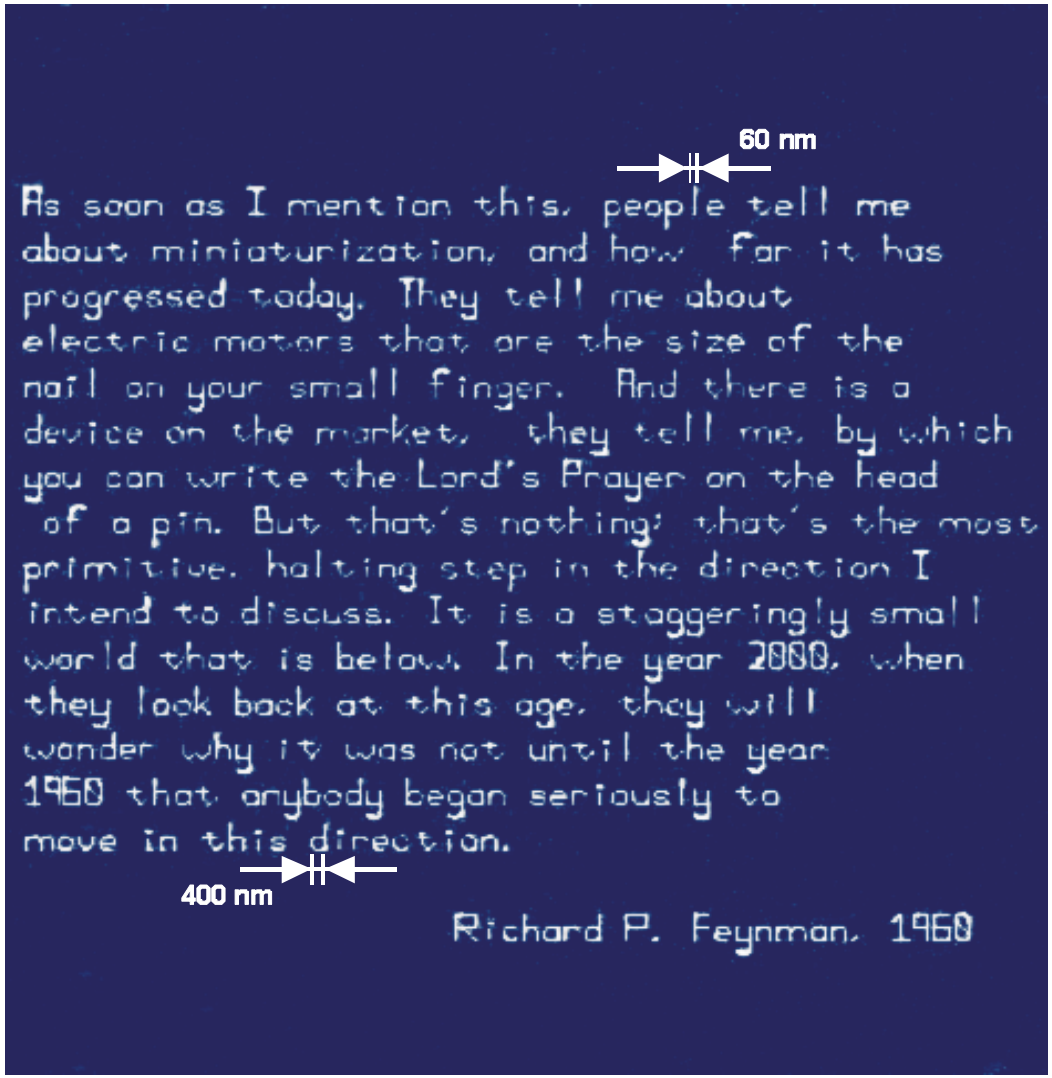
Silicon Nitride AFM Tip



Attributes of DPN

- Direct-write
- Positive printing
- High resolution
  - 10 nm linewidth resolution
  - ~5 nm spatial resolution
- Monolayer process
- Molecule general (organics and biomolecules)
- Substrate general (Au, SiO_x, GaAs)
- Multiple functionalities on one ‘nano chip’
- Writing and imaging done with same tool
- Serial or parallel process
- Amenable to Massive Parallelization

An Automated Nanoplotter



The Evolution of the Pen

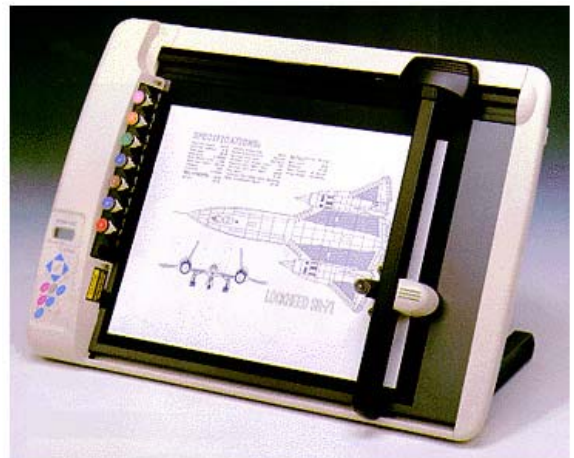
Macroscopic Pens

Quill

Fountain

Ball-Point

Multi-Pen Plotter

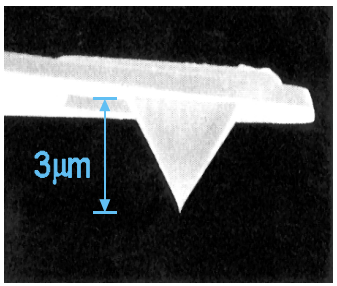


4000 years old **120 years old** **60 years old** **20 years old**

The Evolution of Dip Pen Nanolithography

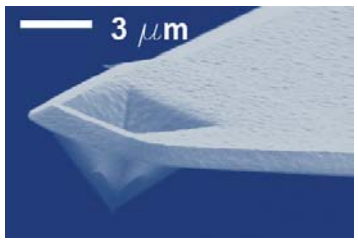
Nanoscopic Pens

"Quill"



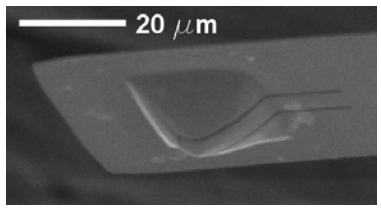
1999

"Fountain"



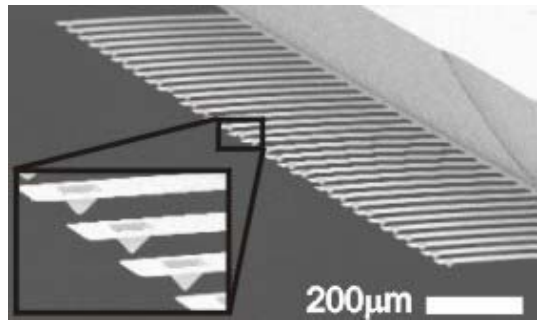
2000

"Ball-Point"



2000

32-Pen Nanoplotter



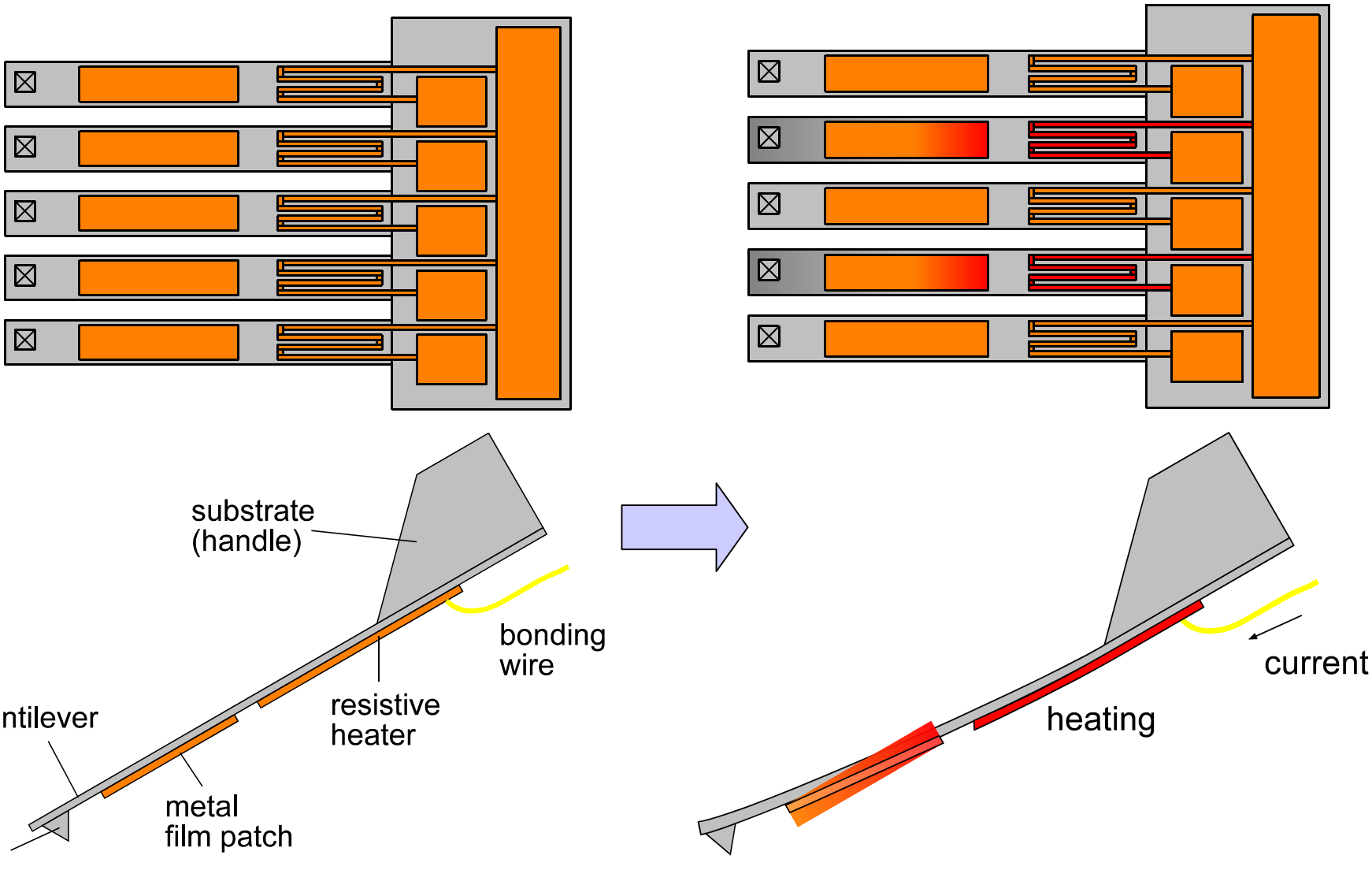
2002

How far can we go?

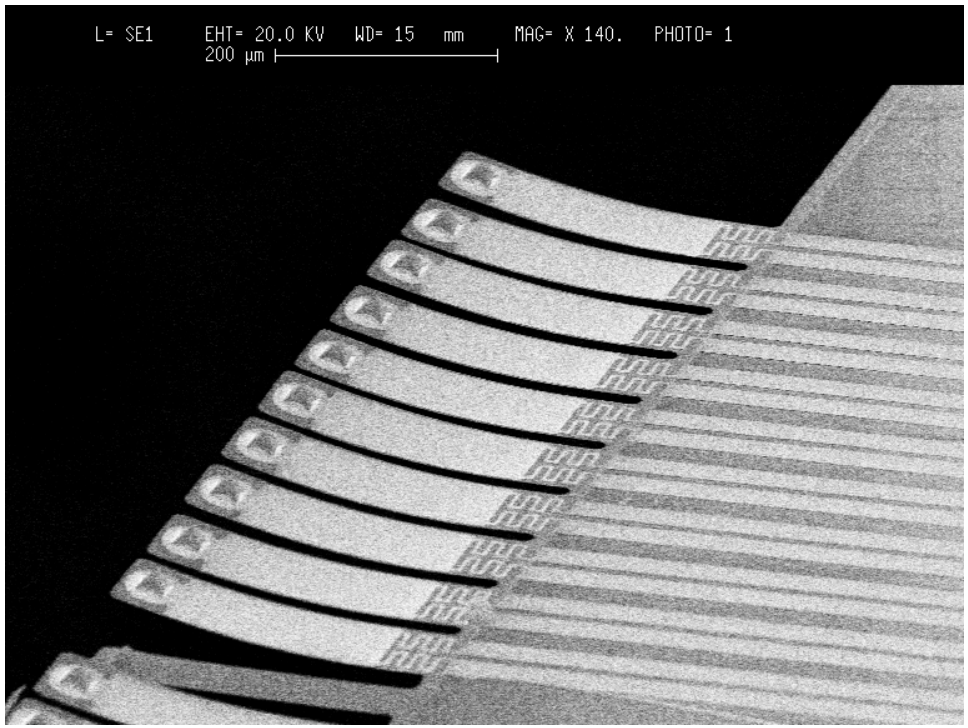
2003

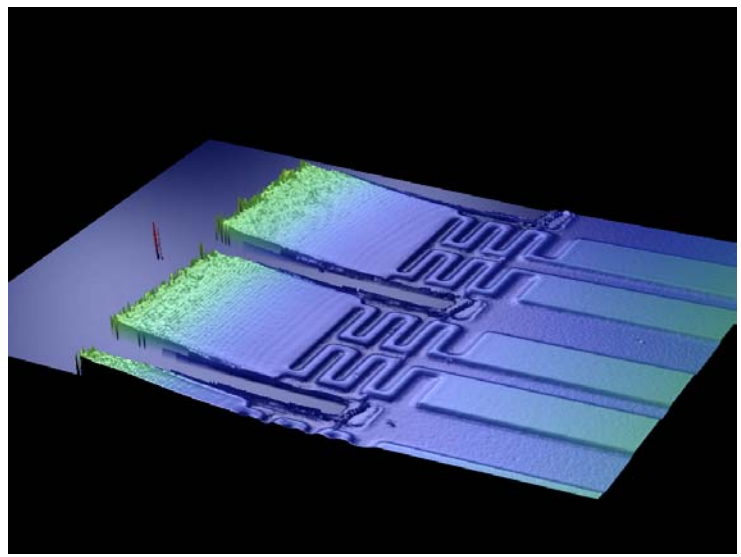
??

Thermal Bimetallic Actuation



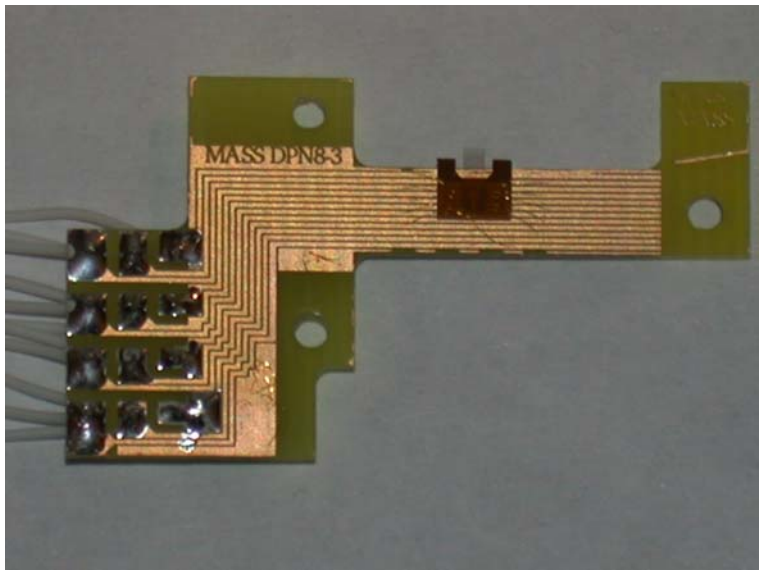
Silicon Nitride Thermal Actuators

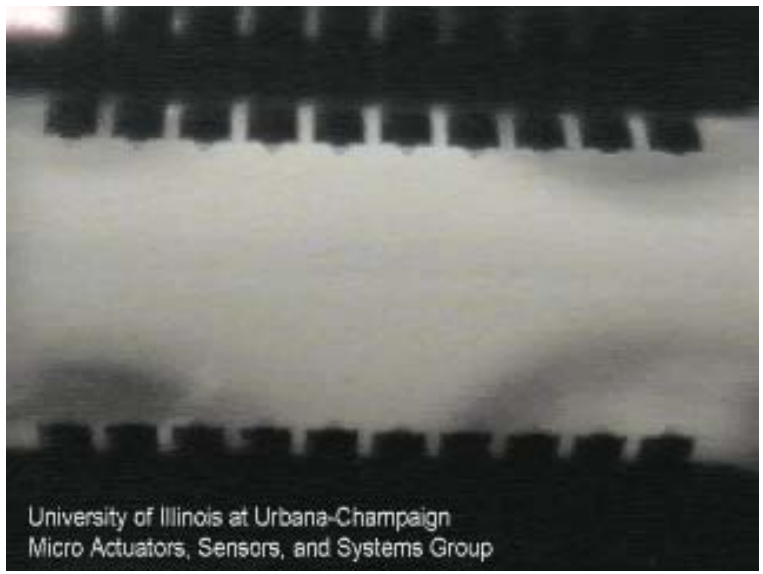




Probes are made of SiN thin film and the heaters are made of Au on a Cr adhesion layer.

Real-Time Video of Active Probes



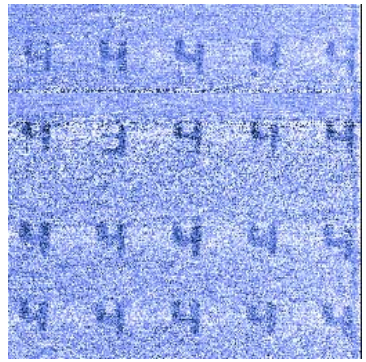


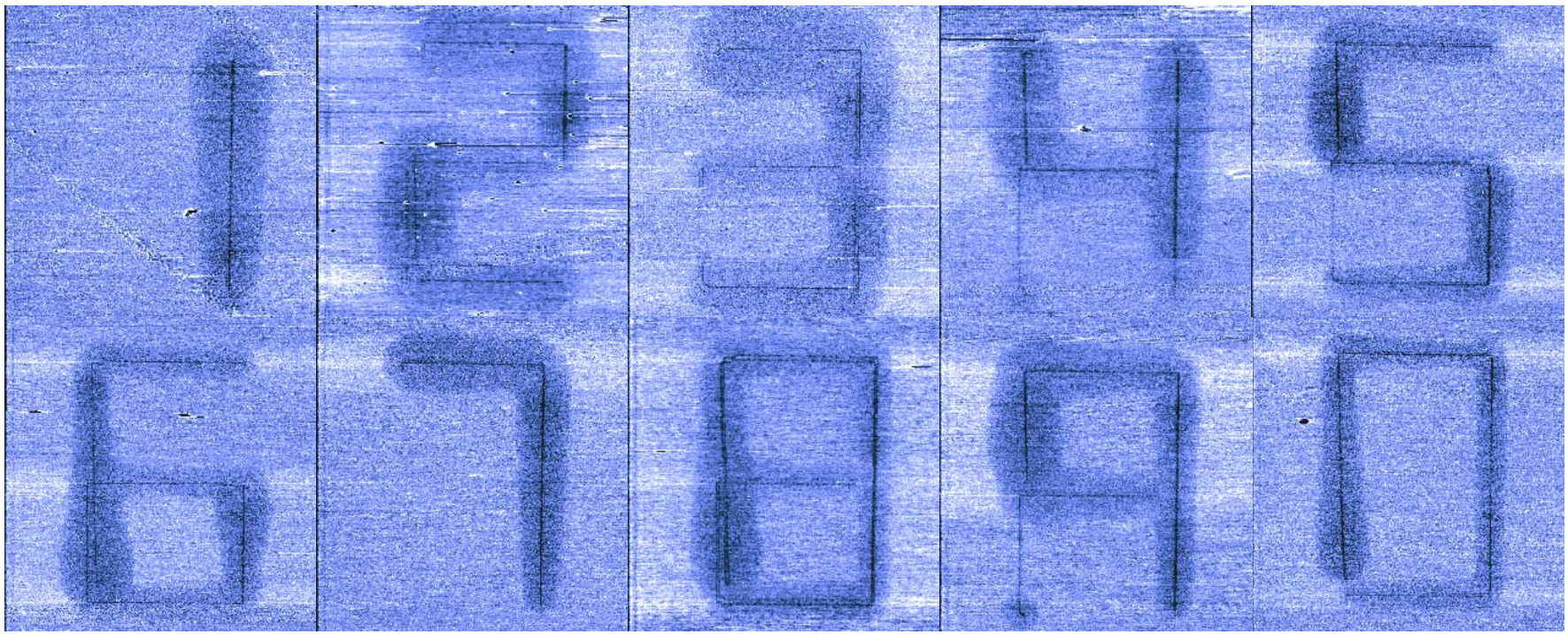
Active TA-DPN Probe Lithography

Characters are 6um tall x 4um wide, ODT on gold.

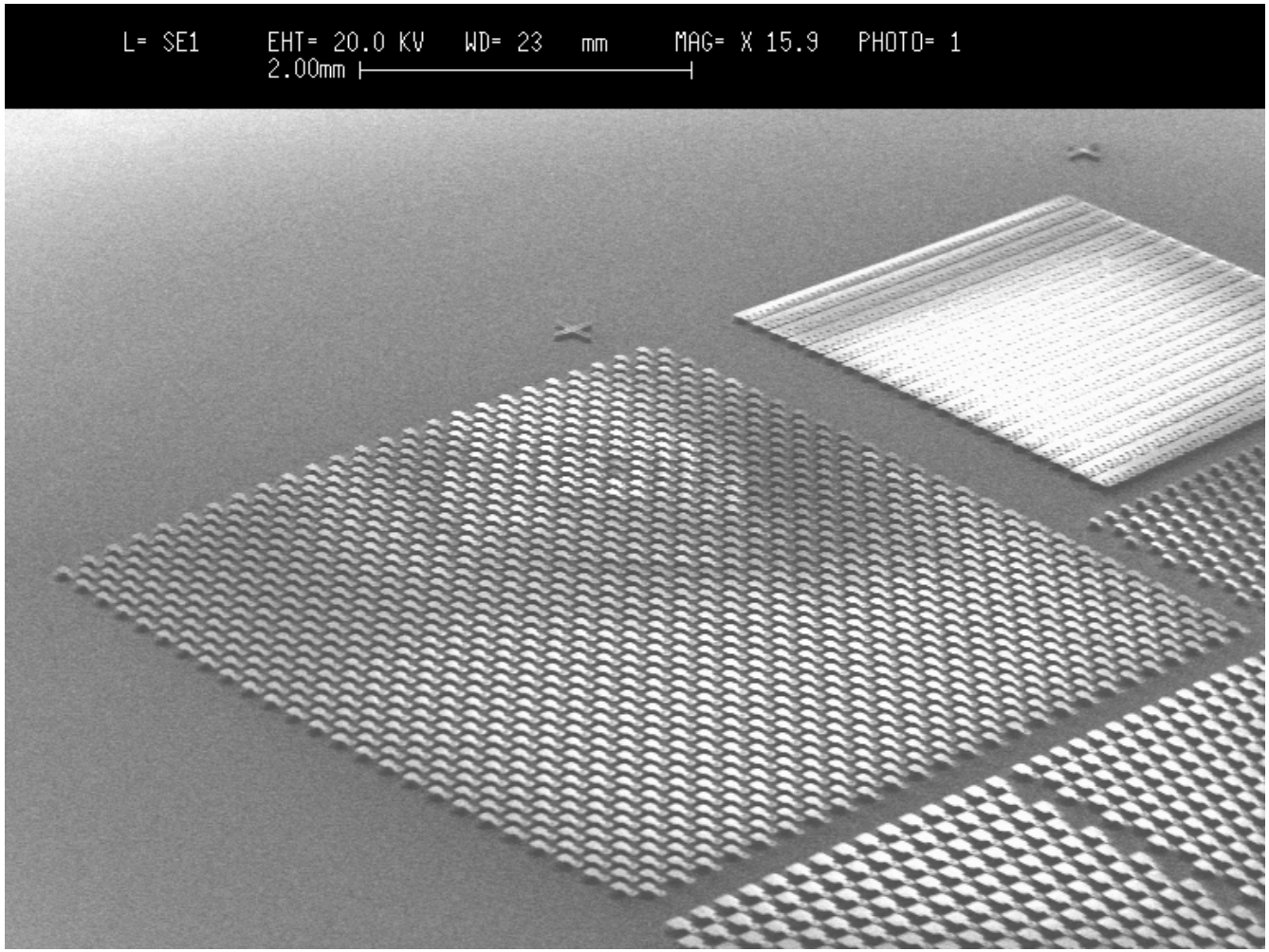
The scans are 8um x 8um. The block to the right is 70um x 70 um.

Written simultaneously at 1um/sec.

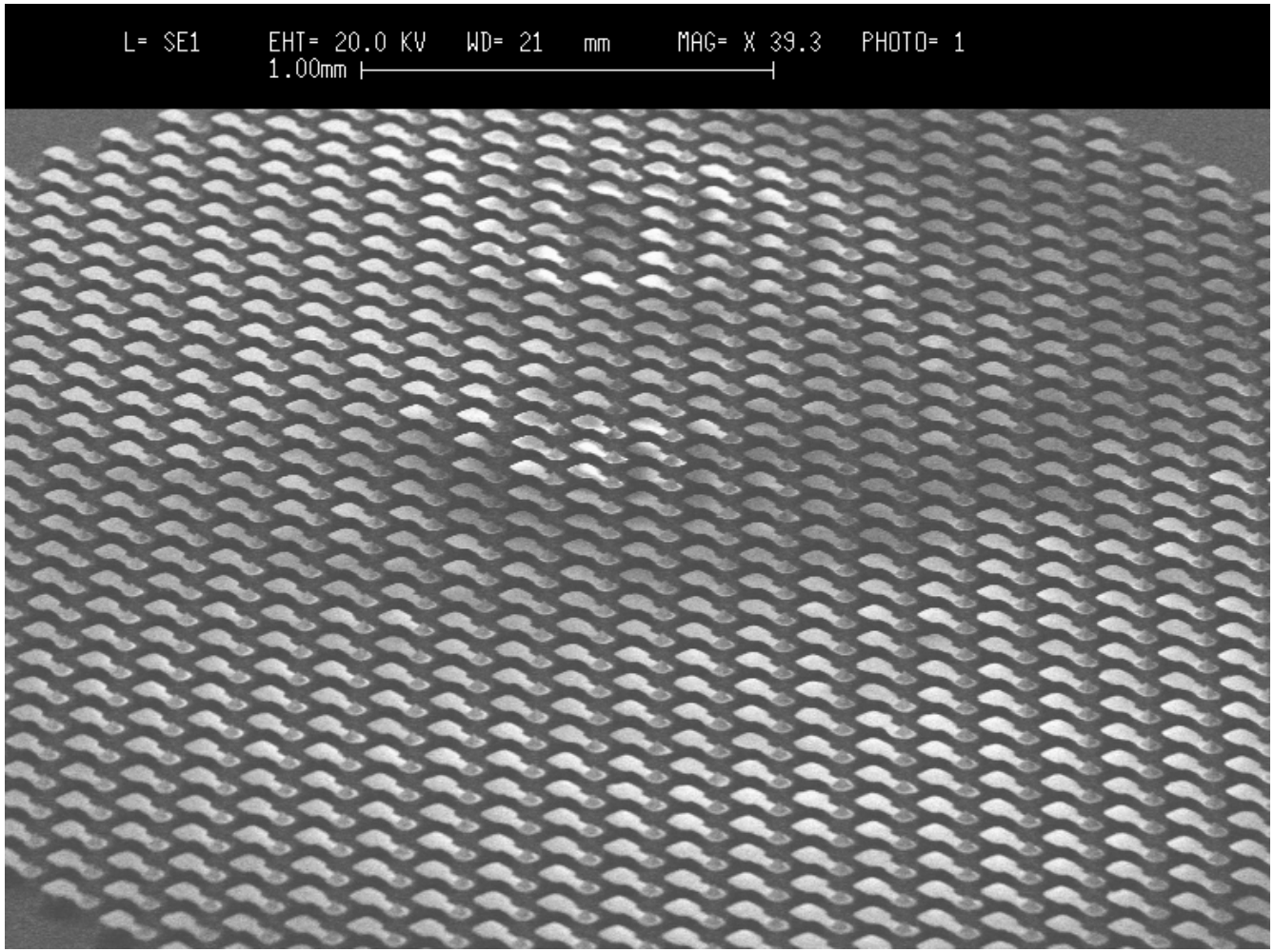




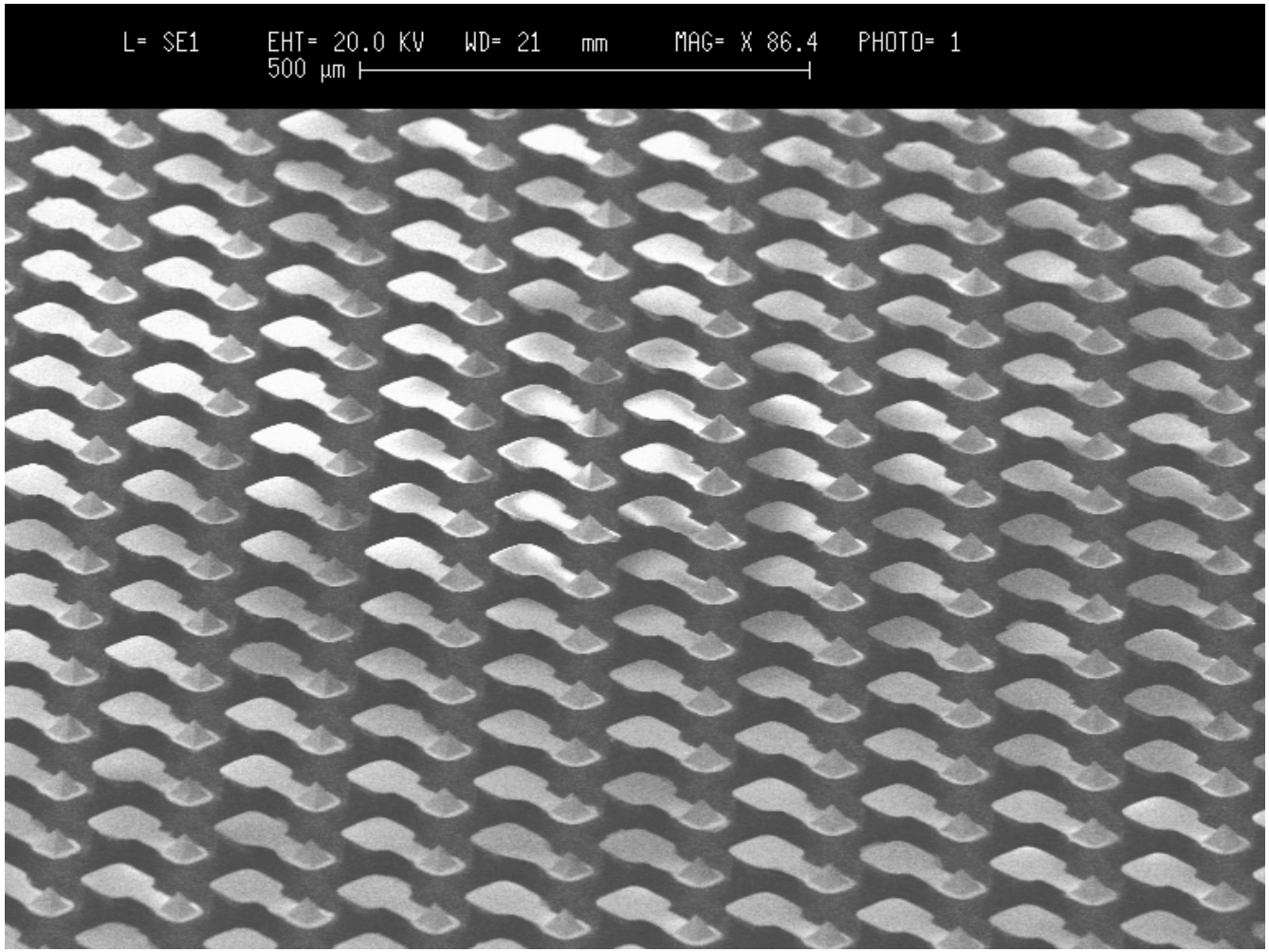
How Far Can We Go? SEM Photos of 2d Probe Array



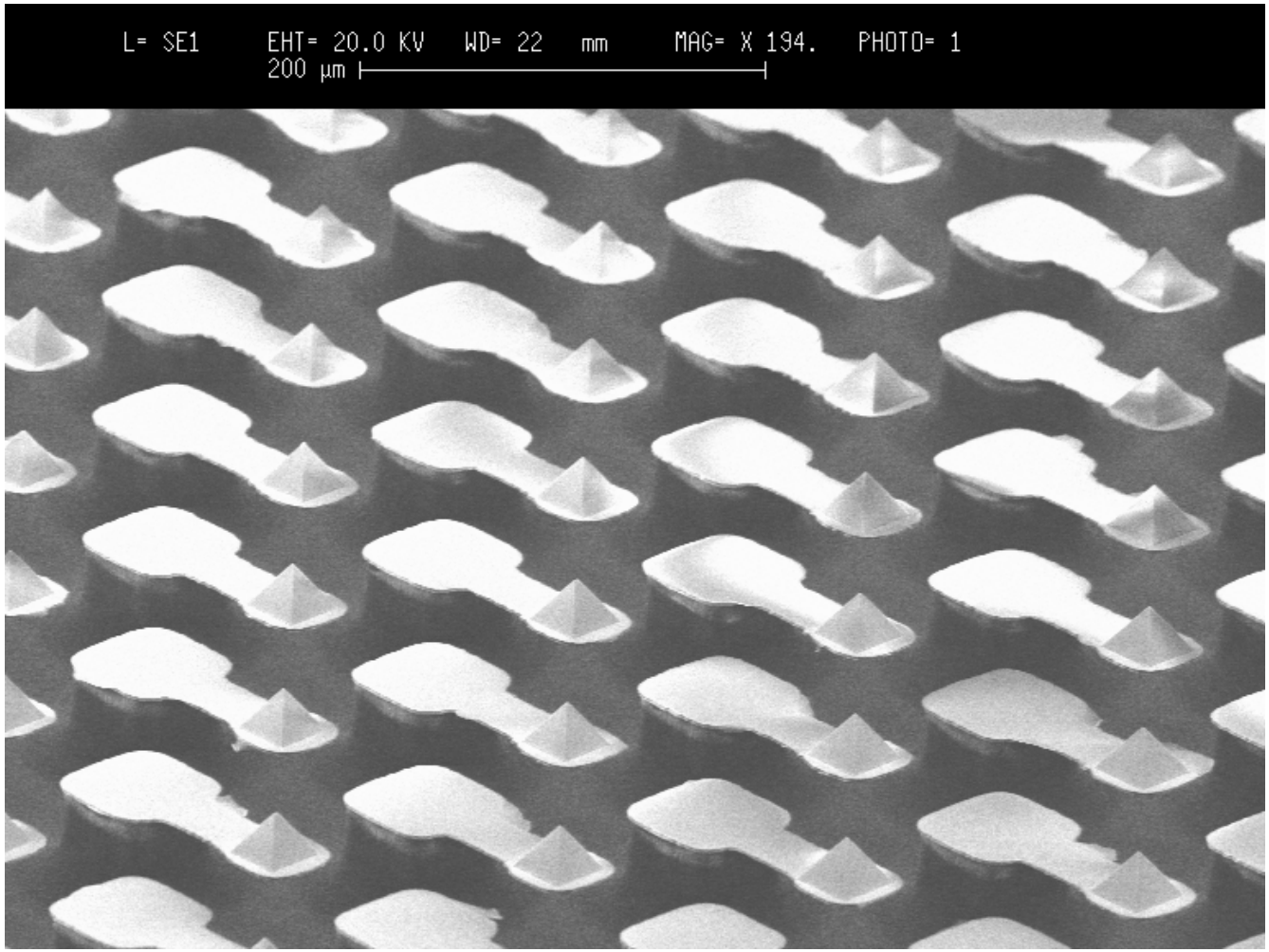
How Far Can We Go? SEM Photos of 2d Probe Array



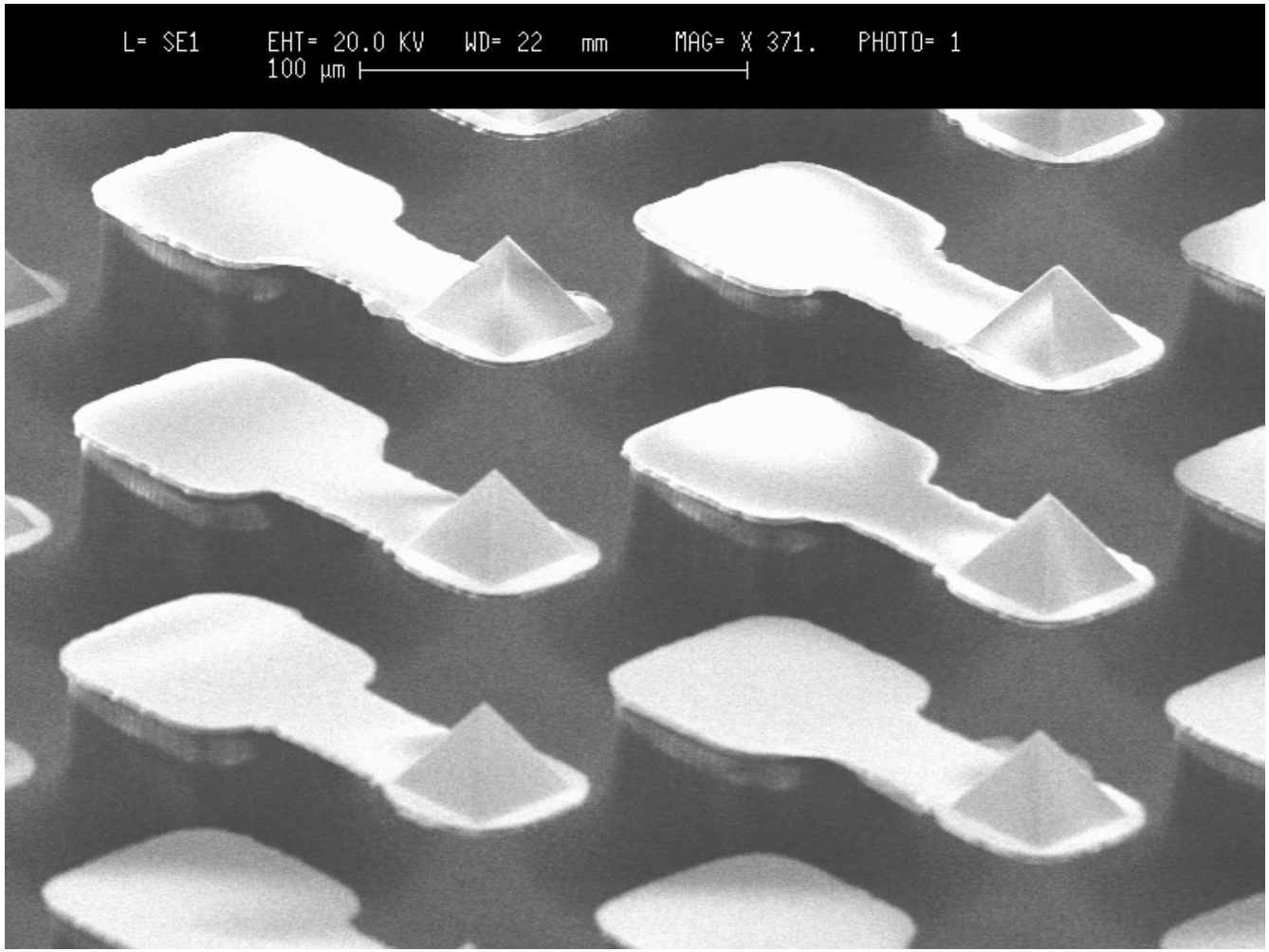
How Far Can We Go? SEM Photos of 2d Probe Array



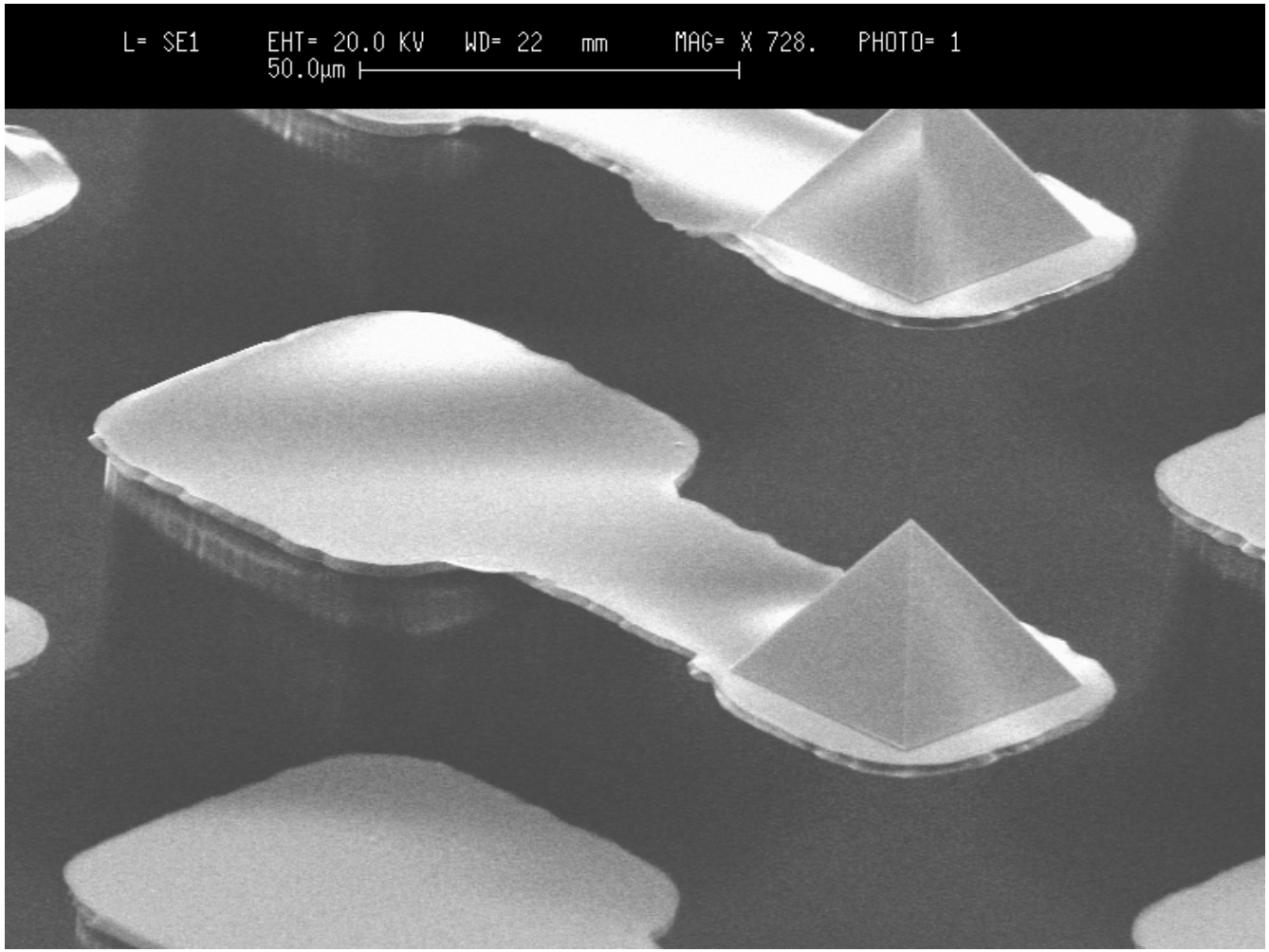
How Far Can We Go? SEM Photos of 2d Probe Array



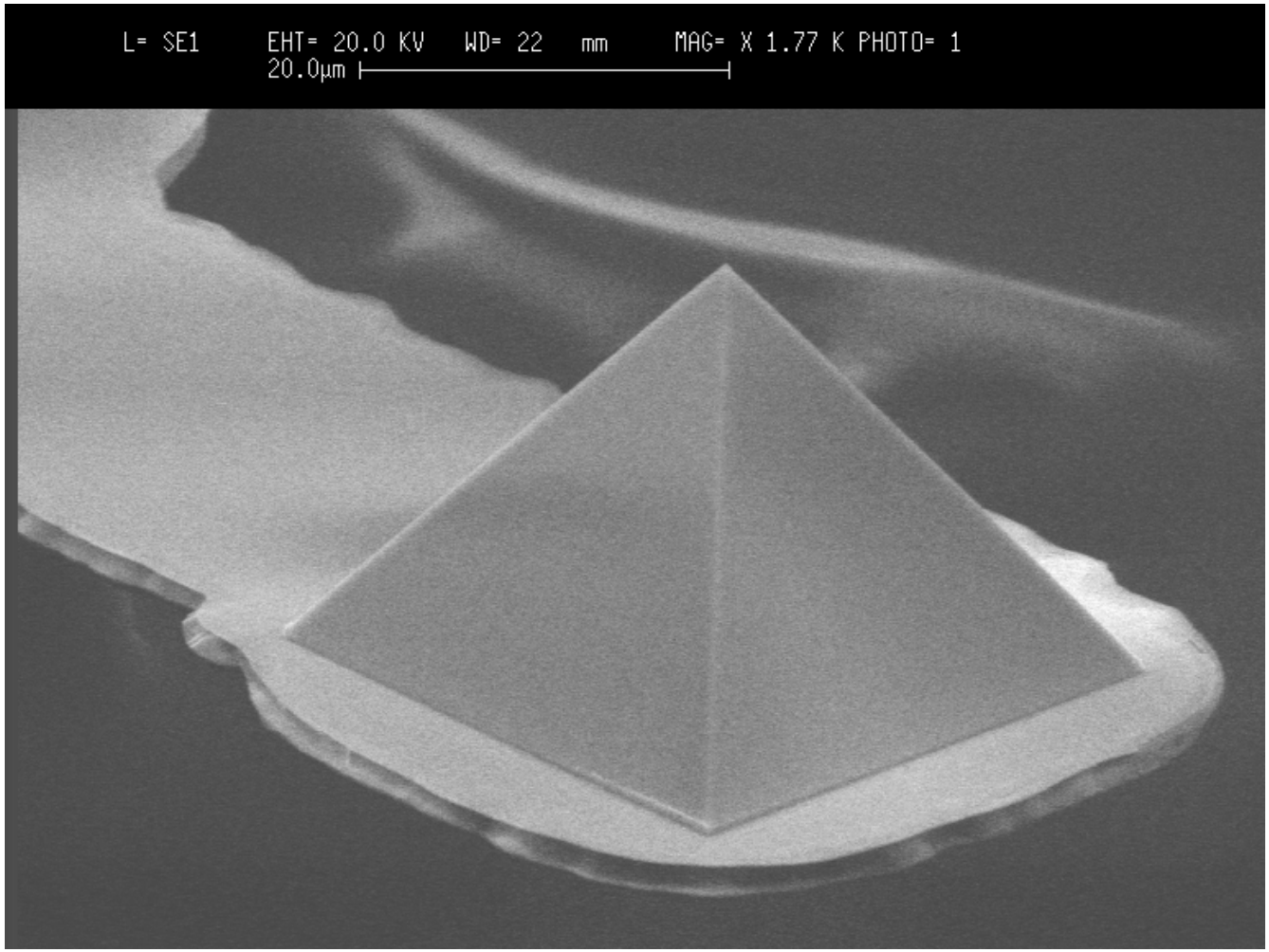
How Far Can We Go? SEM Photos of 2d Probe Array



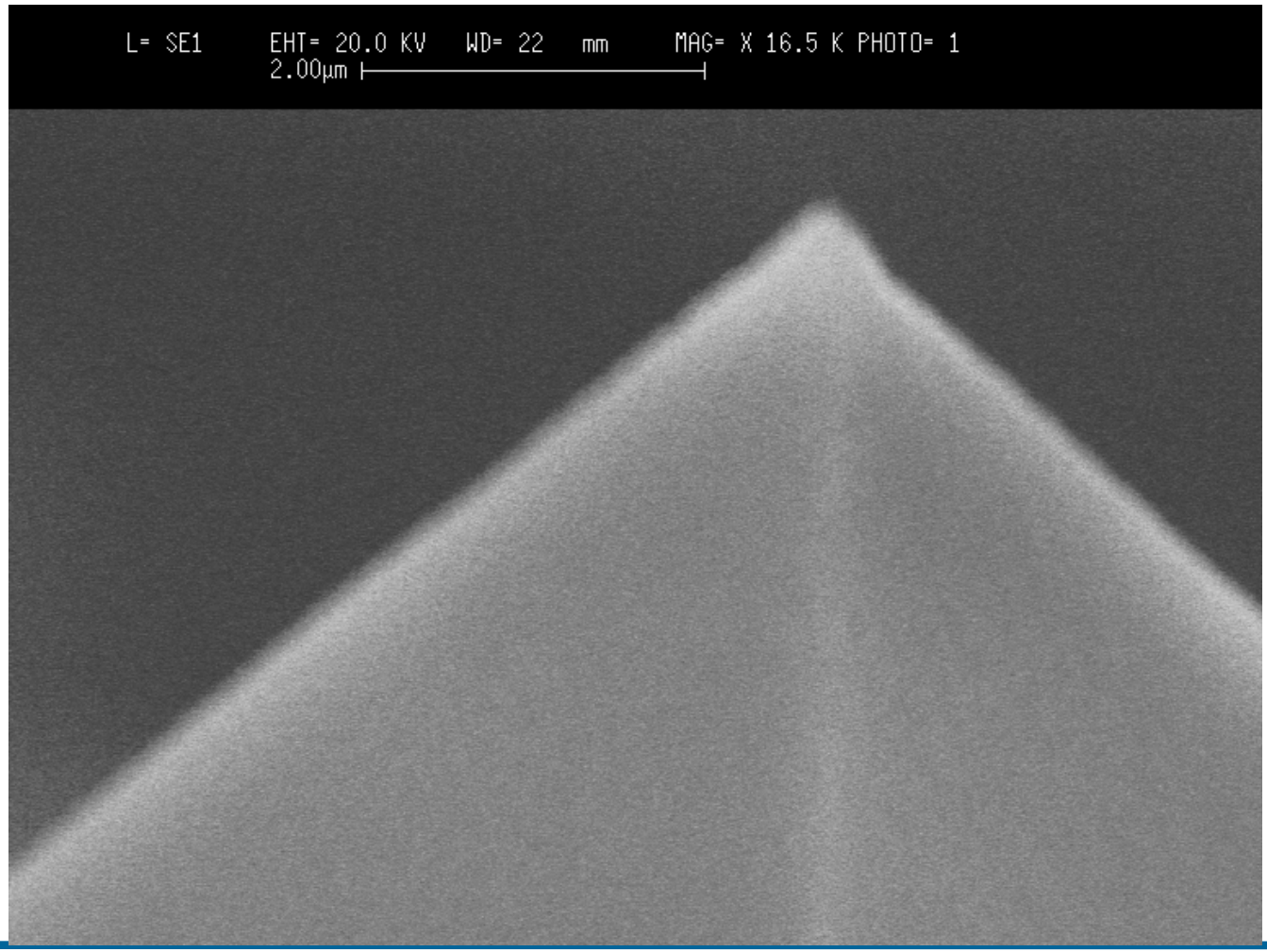
How Far Can We Go? SEM Photos of 2d Probe Array



How Far Can We Go? SEM Photos of 2d Probe Array

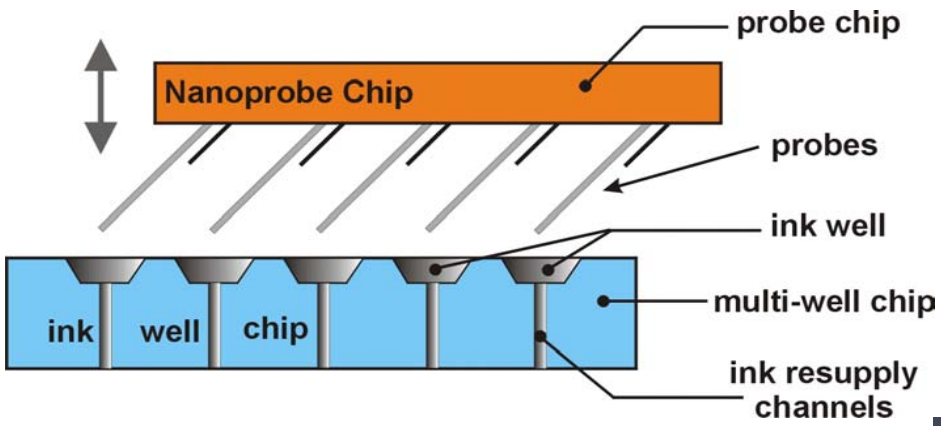


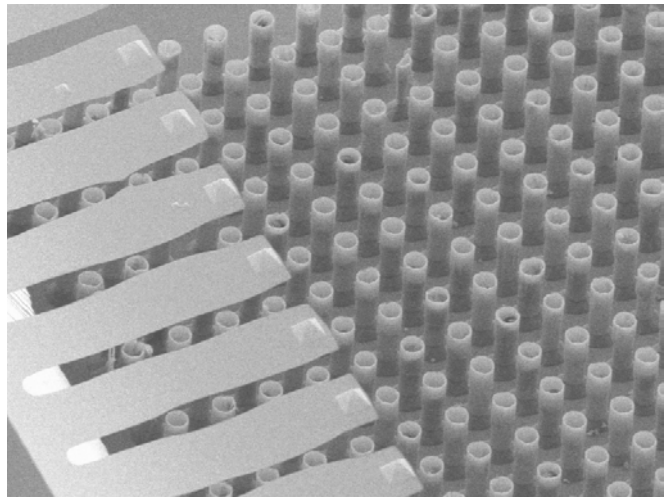
How Far Can We Go? SEM Photos of 2d Probe Array

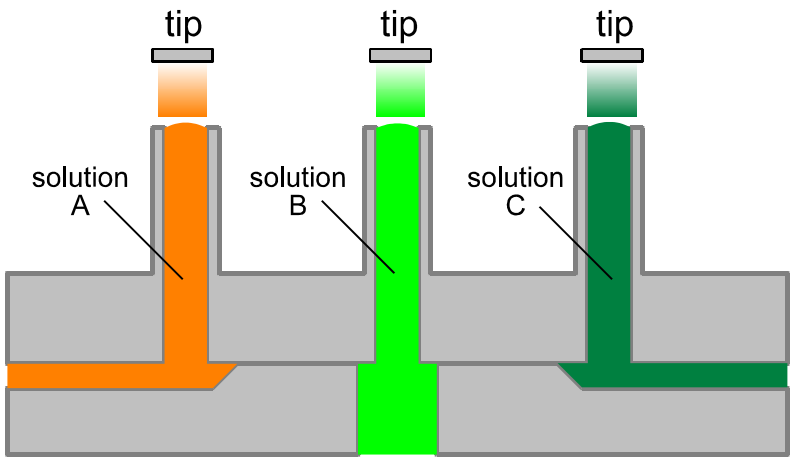


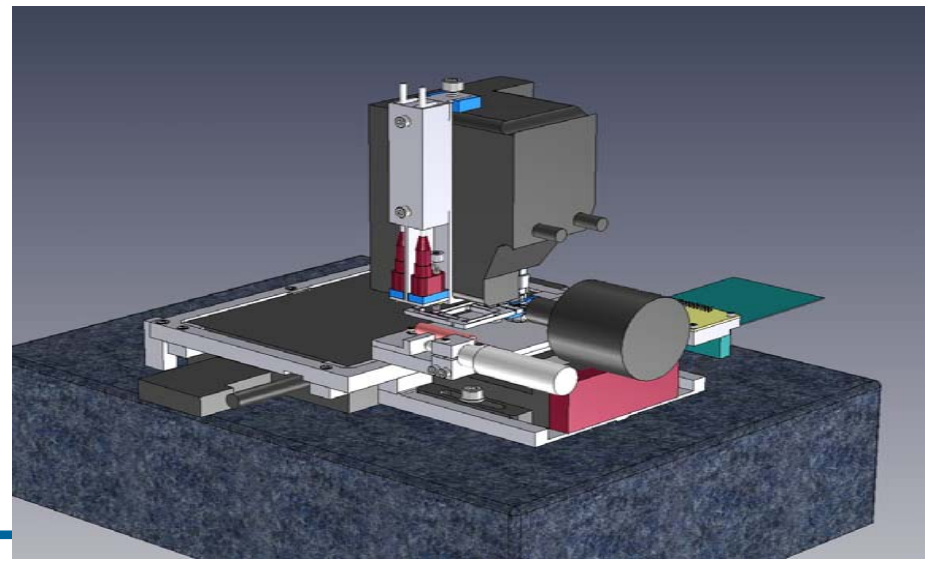
An Integrated Inking System

Microfluid system delivers chemicals to inking apertures







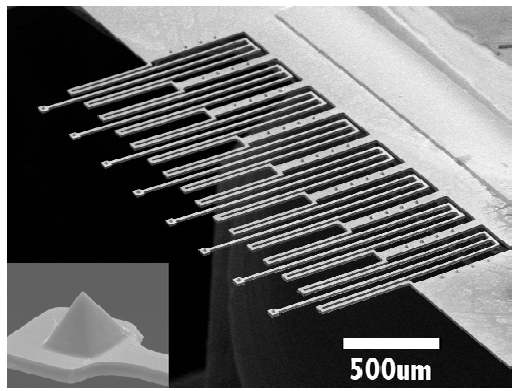


Applications

A tool for studying the consequences of miniaturization

Nano- and microfluidics

Crystallization (colloidal crystals, biostructures)



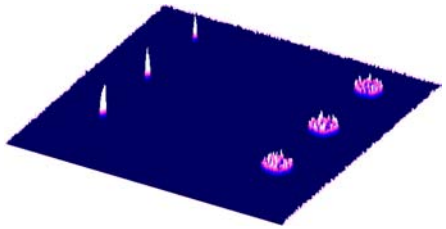
Cryptography

Nanoprinted catalysts

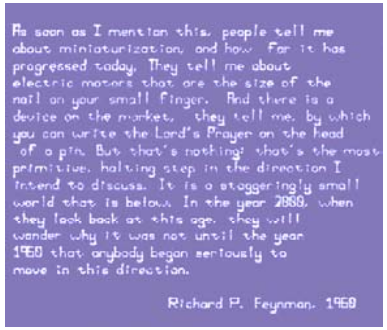
Ultra-small sensors

Molecular electronics (organic, bio-organic circuits)

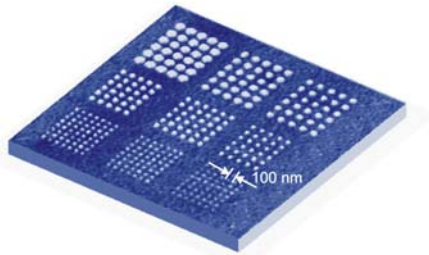
Gene Chips and proteomic arrays



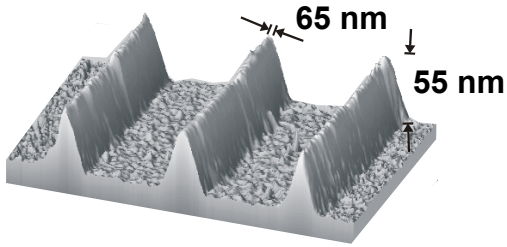
Orthogonal Assembly of Nanoparticles



Flexible Nanolithographic Capability

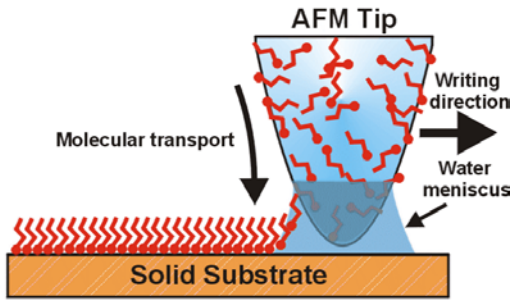


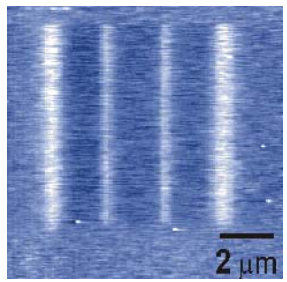
Combinatorial DPN Templates



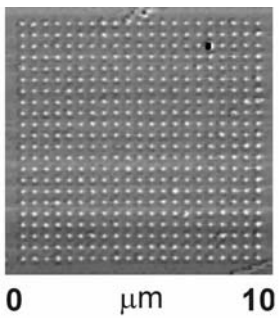
Silicon Nanostructures

Dip-Pen Nanolithograpy



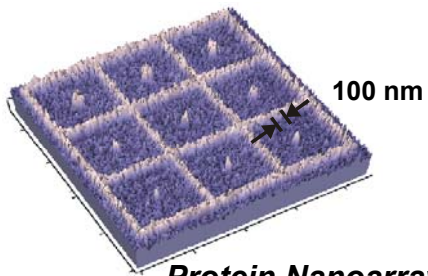


Polymer precursors

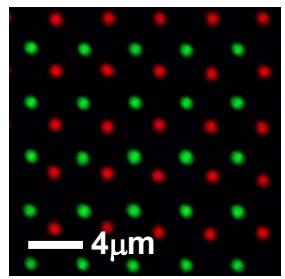


Nanomagnetics

Capabilities



Protein Nanoarrays



Ultrahigh Density DNA Arrays

Super Gene Chip

4^{17} 50 μm diameter dots with 50 μm spacing

Tennis court

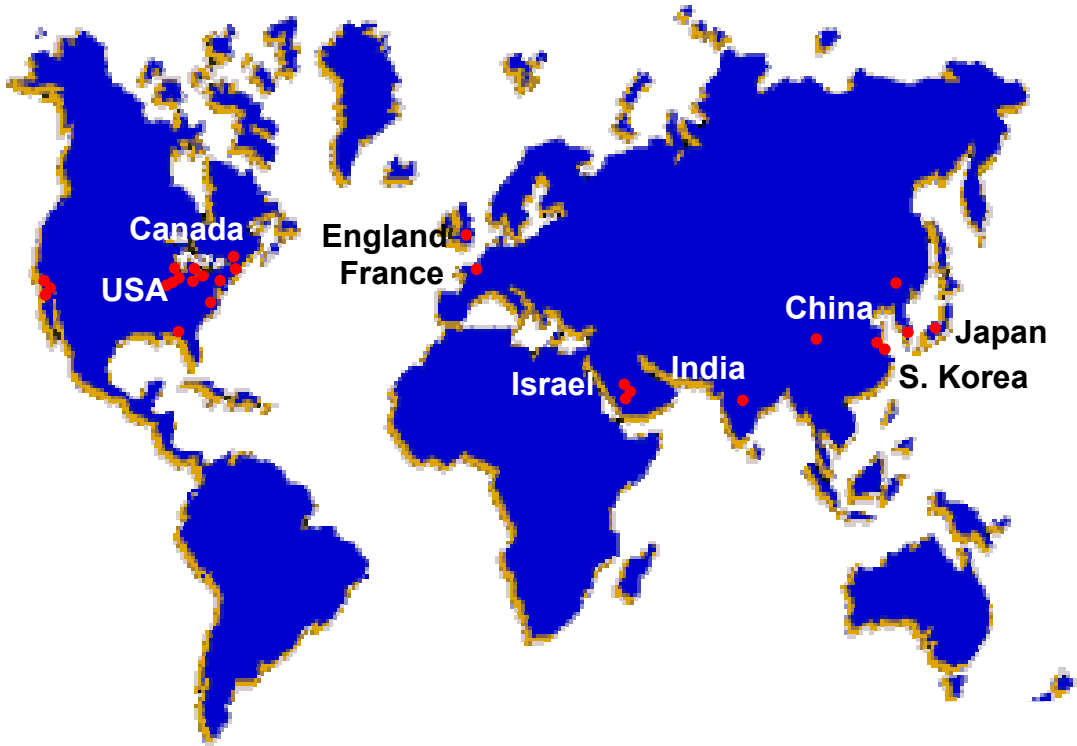
13m x 13 m:
Too big to be practical

4^{17} 50 nm diameter dots with 50 μm spacing

Penny

13 mm x 13 mm:
Reasonable

World Use of Dip Pen Nanolithography



- **Laboratories Using Dip-Pen Nanolithography**